Recreational Boat Collision Accident Research

Volume 1

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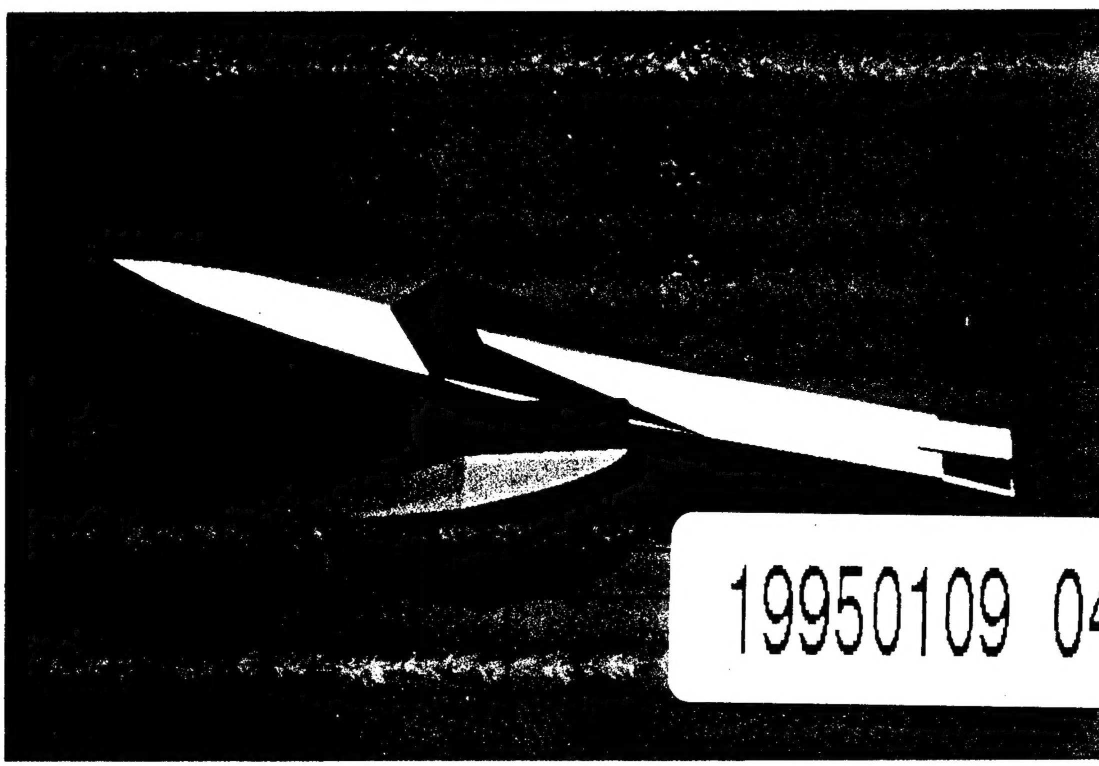

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This project is the result of the efforts, contributions, and talents of a great many individuals, companies, states, and agencies. It is not possible to list all those that contributed, but special thanks is given in these paragraphs to those who were especially important to the success of this project.

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Miles Beam

ABBREVIATED TABLE OF CONTENTS

Volume I

VOLUME II - APPENDICES: COMPUTER SIMULATION DATA

DETAILED TABLE OF CONTENTS
Volume 1

CHAPTER 4

CHAPTER 5

CHAPTER 8

CHAPTER 9

CHAPTER 10

CHAPTER 11

CHAPTER 12

CHAPTER 13

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ABSTRACT

This report is the result of three years of research on the subject of recreational boat collision accident reconstruction. The primary focus of the report is to develop techniques for reconstructing boat collision accidents based on physical evidence. The purposes and goals of the project are outlined in Chapter 1.

Chapter 2 examines the USCG Annual Statistics on recreational boating to examine trends and problems over the last twenty years. Despite an overall decrease in the fatality rates in recent years, the number of reported collision accidents has increased. While the number of fatalities from capsizings and falls overboard has decreased each year, the number of fatalities from collisions has stayed the same or increased slightly. The conclusion from this data is that collisions are becoming more common and will probably continue to account for an increasing percentage of the accidents and fatalities in future years.

Chapter 3 presents an analysis of the three types of collisions, Collisions With Another Vessel (CWAV), Collisions With a Fixed Object (CWFXO) and Collisions With a Floating Object (CWFLO). The analysis of these accident types was conducted over a twenty period to examine trends. CWFXO accidents account for on average, about the same number of fatalities as CWAV accidents, even though there are far fewer occurrences of CWFXO accidents. Accidents classified as CWFLO account for less than 20 fatalities per year.

In Chapter 4, a review of more than 50 fatal collision accident reports was conducted to look for trends and common denominators which are not necessarily recorded in the statistics. The results of this limited sample showed some interesting trends. In CWAV accidents, persons are more likely to be injured or killed if they are in the smaller of the two vessels or in the struck boat as opposed to the striking boat. The occupants are at an especially great risk of injury if they are in the smaller boat and it is also the struck boat. Occupants in collisions risk being thrown overboard. It is important to determine if a victim died as a result of injuries suffered in the accident or from drowning. Current accident reports do not always answer this important question. In reports that did cover this area, it was discovered that most drowning victims were not wearing PFDs. In the limited sample studied, 15 out of 16 powered boats involved in a fatal CWFXO accident were by powered by outboard engines. A fairly even mix of propulsion types between outboards and I/Os was found to be involved in CWAV accidents.

The differences in environments between the boat and the automobile are important to understand, and are discussed in Chapters 5 and 6. Differences are found not only between boats and automobiles, but in the operator's backgrounds and qualifications as well. While the automobile operator must pass a written test and an operator's test, and have minimal physical capabilities to posses a license, none of these restrictions apply to boat operators in most states.

The investigator cannot make any assumptions about the age or qualifications of the boat operator involved in an accident. The boater's environment can take its toll physically on an operator. Sun, wind, vibration, and general exposure to the elements can cause fatigue and impair judgement.

Chapter 7 and 8 examine the field of automobile collision accident reconstruction. This field is perhaps most closely related technically to boat collision accident reconstruction. Many of the techniques that are used in constructing an automobile accident, as well as the physics that apply, can be directly applied or adapted to the reconstruction of boat accidents. The fundamental physical principles of boat accidents are examined in Chapter 7. Much of this data is derived from experimental collisions conducted in 1988 and 1989 by UL prior to the beginning of the USCG sponsored research. Most of these collisions were conducted as part of a training exercise or accident investigation seminar conducted for the Florida Marine Patrol. Chapter 8 examines common techniques used in automobile accident reconstruction and discusses their relevance to boat accident reconstruction.

Chapter 9 discusses the common types of boat interaction during a collision accidents. These methods of interaction, such as over-rides and glancing blows, play a large role in determining the severity of the accident. This chapter discusses possible methods for using this type of information in developing an accident classification system. The goal of this system would be to easily identify accident types or scenarios which tend to result in the greatest number of fatalities or which presents the greatest risk of a fatality. This information could be used by the USCG, state boating law administrators, educators and boat manufacturers to identify where the greatest efforts need to be focused to reduce fatalities in collision accidents.

Chapter 10 provides the investigator with an understanding of the types of damage found in a typical collision accident. Techniques for documenting the various types of damage are discussed.

Chapter 11 provides a theoretical approach for estimating speeds for certain types of accidents. The earliest efforts by UL in this area centered around the trajectory motion equations. These equations are applied to boat collisions in which the boat is airborne. These formulas are useful if it can be documented that the center of gravity (CG) of the boat traveled through the air a certain height and/or distance.

Chapter 12 presents some theoretical methods for estimating impact angles and relative velocities of two boats involved in a collision. These techniques apply primarily to over-ride type collisions, in which the striking boat rides over part or all of the struck boat. Concepts are presented regarding the Minimum Threshold Velocity (MTV), which is the minimum velocity required for one boat to ride over a second. The possibility of using the geometry of the collision and the shape of the boats' hulls may form the basis for actually predicting the launch angle of the bullet boat in an over-ride collision. Depending upon what other

data is available, these concepts may help to more accurately estimate the minimum possible speed of the striking boat in an over-ride accident. These concepts need further development, but may serve as the basis for future study.

Chapter 13 provides the results of ten field accident investigations. Each accident is used as a teaching tool. The discussion focuses on the damage or information that is unique to that particular accident, which helped the most in the reconstruction. This chapter is not intended to serve as an example of how to write accident investigation reports.

Chapter 14 pushes the limits of current technology and provides a glimpse of what the future may hold. We conducted computer simulation of a simple collision accident. The scenario simulated a boat striking a stationary boat at a ninety degree angle. The striking boat speeds were varied from 5 to 30 mph in 5 mph increments. The simulation was a feasibility study and the complexities and limitations of today's technology were quickly realized. The latter part of the chapter discusses the potential usefulness of utilizing computers in future boat collision accidents.

Volume 2 contains data relating to the computer simulation. The data is useful primarily to researchers, scientists, and accident reconstruction experts interested in computer simulation.

LIST OF ABBREVIATIONS

a = acceleration

ASC = Accident Severity Code

ASI = Accident Severity Index

Bullet Boat - In a two boat collision accident, the bow of this boat generally strikes the other vessel. Also referred to as Boat No. 1, or the striking vessel.

CG = Center of Gravity

CHR = Center of Hydrodynamic Resistance

CLR = Center of Lateral Resistance

CR = Center of Rotation

CWAV - Collision With Another Vessel

CWFLO - Collision With a Floating Object

CWFXO - Collision With a Fixed Object

d = distance

D = drag factor

f = friction

F = force

ft = feet

g = acceleration due to gravity (32.2 ft/sec^2)

h = height

I = mass moment of intertia

KE = Kinetic Energy

m = mass

mph = miles per hour

N = normal force

OB = overboard (as in thrown overboard)

OIC = Occupant Injury Code

OFC = Occupant Fatality Code

over-ride - A type of collision accident where the striking boat literally rides over part or all of the struck vessel.

PE = potential energy

PFD = Personal Flotation Device

RPM = Revolutions per Minute

sec = second

striations - Marks on a surface which indicate that contact with another surface occurred that had some positive relative velocity. These marks generally appear in the form of scratches or scrapes.

Target Boat - This is the boat which was considered to be struck by the bow of the other vessel. Also referred to as Boat No. 2, or the struck boat.

T = torque

u = coefficient of friction

V = Velocity

VR = Velocity Ratio, the ratio of speeds between the bullet boat and the target boat, or V2/V1.

W = weight

CHAPTER 1

INTRODUCTION

1.0 Why Study Collision Accidents?

The number of recreational boats on the nation's waters has been increasing steadily for at least the last 20 years. Yet, according to the annual boating statistics published by the United States Coast Guard, the number of fatalities has been generally decreasing each year. In spite of this good news, there are still signs of congestion associated with the growth of the boating population. A possible indication that the waterways are getting more crowded each year is the increasing number of collision accidents. In recent years, according to the USCG annual statistics, collision accidents have accounted for approximately half of all the accidents reported and involved more than 60% of all vessels involved in an accident.

Even though collision accidents are a major problem in the picture of boating safety, they are perhaps the least understood and most difficult type of accident to investigate and reconstruct. This fact has been confirmed by conversations with literally hundreds of law enforcement accident investigators over the past four years. These officers, who have taken the Boating Accident Investigation Seminars offered by UL under a grant from the USCG, have generally confirmed that collision accidents are probably the most difficult accident type to accurately reconstruct. Little or no formal research has been done in the past to develop techniques for boating collision accident reconstruction. Therefore, law enforcement officers who must investigate collision accidents usually have little training in the specifics of collision accident investigation and reconstruction.

Other implications of the lack of prior research in this area are that little is known about collision dynamics. Detailed information is simply not available regarding exactly what happens to the boats, the internal structure, and more importantly to the occupants, when a collision occurs. Research into these areas is necessary in order to reconstruct accidents, and ultimately to improve boating safety.

1.1 What Can Be Learned By Studying Collision Accidents?

The ultimate goal of studying any accident is to learn how to prevent that accident from occurring again, and if it is not preventable, how to minimize the potential risk of injury or death. The study of collision accidents is no different. Serious effort has been made in the past to study boating collision accidents. Previous efforts concentrated on cause and prevention of collision

accidents. A list of relevant studies is provided at the end of this chapter. This study focuses on the accident process and all that it involves. By studying collision accidents, we hope to learn how to reconstruct those accidents.

In addition, we hope to learn more about where to concentrate future efforts on improving boat design (if necessary), and protecting occupants. We hope to identify the most common and/or deadly accident scenarios to form a basis for how to prevent these accidents. A natural first step is to study the dynamics of these collisions and learn how to reconstruct these accidents. The resulting information will provide tools and resources to the boating industry, designers, and law enforcement personnel.

1.2 What About "Crashworthiness" ?

Inevitably when the subject of boating collision accident research surfaces, people ask questions about "crashworthiness" of recreational boats. Visions of boats driving into concrete barriers, dummies appearing on commercials wearing aquatic seat belts, and new government agencies forming specifically to regulate boat crash tests dance in the anxious minds of manufacturers and the curious minds of boaters. In order to put this issue into its proper perspective, we must first understand what crashworthiness really is and how it relates to boats.

Crashworthiness, in the practical sense, refers to the degree to which the vehicle (boat or otherwise) is resistant to the effects of a crash. A more relevant term to describe the key area of concern as it relates to boating safety is occupant protection. Occupant protection might be defined as how well the vehicle protects the occupants during a collision. This is the primary concern with regard to boats. The crashworthiness of the vessel is also important, but only as it pertains to maintaining some degree of seaworthiness after an accident to prevent loss of the vessel and those on board.

Common misconceptions about crashworthiness imply that a boat should withstand a collision without suffering major damage. Automobile manufacturers learned long ago that they could design a really strong vehicle that would suffer small amounts of damage during a crash, but the forces that the occupants experienced could be fatal. Today's automobiles provide excellent occupant protection during a frontal crash partly through energy management techniques. By allowing the vehicle structure to deform as the crash occurs, and thereby absorb energy as the crash progresses, the forces exerted on the occupants are kept to as low a level as possible. Additional means of occupant protection are padding of surfaces, collapsing steering columns, and of course, active and passive passenger restraints. Some of these techniques, or variations thereof, may eventually apply to boats. Recommendations of changes in boat design are beyond the scope of this project. There may be

times however, when design features which are either apparent problems or have contributed significantly to an accident or injury will be identified. If sufficient information is present in the cases studied, hypotheses concerning boat design as it relates to occupant protection may be presented. Before anyone can adequately address the issues of occupant protection, we must have a greater understanding of exactly what is happening to the boat and its occupants during a collision accident.

1.3 Scope

This investigation is limited to the study of collisions involving recreational boats. All types of collisions are considered including the three types identified by the USCG annual statistics. These types are as follows: Collision With Another Vessel (CWAV), Collision With a Fixed Object (CWFXO), and Collision With a Floating Object (CWFLO). The abbreviations for the various accident types in parenthesis will be used extensively in this report.

No specific restrictions have been placed on the length of boats involved. That is, accidents were investigated or analyzed statistically regardless of the length of vessel. The majority of accidents studied were considered to be representative of most field accidents with regard to boat length.

In the section on statistics of collisions, the two other major accident types, based on fatalities, of falls overboard and capsizings were considered and compared to collision accidents in order to obtain a better overall view of accident trends for the period covering 1970-1989.

1.4 Purpose

The overall purpose of this project is to better understand collision dynamics and occupant kinematics in collisions involving recreational boats for the purposes of accident reconstruction and improving boating safety.

1.5 Goals and Objectives-

Some specific goals and objectives of this investigation are outlined below.

Goal No. 1:

Evaluate the significance of collision type accidents in terms of number of deaths and number of vessels involved. Compare trends of collision accidents with trends of capsizings, falls overboard, and other accident types for the last 20 years.

Determine how these trends are changing as the number of boats increases. In addition, evaluate how injuries and deaths occur in boating accidents.

Research was focused on answering the following questions:

How significant is the collision problem?

Has the number of collisions increased over the years as the number of boats have increased?

Are there certain types of collisions or scenarios which commonly occur? If so, can they be avoided?

What collision accident types result in the greatest numbers of fatalities and injuries?

What causes injuries and deaths during collision accidents?

Are there common accidents which seldom result in an injury or death? If so, what are these accident scenarios, and why are occupants not injured?

What can be said regarding future numbers of collision accidents, in particular those involving fatalities?

Goal No. 2:

Explore accident reconstruction techniques that can be used to reconstruct a collision accident. Specifically these included techniques to:

a. Estimate the minimum speed at which the boat was traveling just prior to impact.

b. Determine the angle of impact. This primarily applies to two boat collisions.

c. Identify the accident investigation techniques which could be made available to the field officer today.

d. Identify accident reconstruction techniques and technologies which show promise for future applications but which may need further development.

e. Identify types of collisions accidents and associated reconstruction techniques which need to be further developed.

f. Identify areas in accident reconstruction which are best deferred until technology improves in relevant areas.

g. Determine the role which occupant kinematics can play in collision accident reconstruction.

Goal No. 3

Evaluate the potential applications of techniques and lessons learned from the project as they apply to improving safety.

Research was focused on answering the following questions:

a. What are the primary causes of the collision accidents studied?

b. What are the significant contributing factors?

c. What are possible ways to prevent these accidents from occurring?

d. Is it likely that collision accidents can be prevented?

e. If these accidents are not preventable, what can be done to minimize death and injury?

f. Are today's boat designs adequate for the purposes of protecting the occupants? What are the positive and negative aspects of today's designs regarding occupant protection?

g. What areas need to be addressed regarding occupant protection during collision accidents?

Goal No. 4.

After thorough study and analysis of data obtained on the subject of recreational boat collisions, we should be in a position to draw conclusions and make recommendations concerning the future of collision accidents, collision research, and accident reconstruction techniques.

Research was focused on answering the following questions:

a. What are the primary areas to be addressed in future studies on the subject of collision accident reconstruction?

b. Should boat collision tests be conducted? If so, what types of tests, should be conducted and why? What parameters should be monitored if tests are conducted?

c. Should minimum safety standards for occupant protection be developed?

d. Are collisions likely to become more or less of a problem in the future and why?

1.6 Results of Research Into Related Areas

A literature search into relevant areas was conducted using a variety of sources, databases, libraries, and consultants. Research was specifically conducted in the following areas:

Boat collision research
Automobile accident reconstruction
Computers and computer simulation
Computer aided accident reconstruction
Automobile crash testing
Composite materials, impact testing and damage resistance
Aircraft accident investigations

The primary research performed in the collision area was conducted by Wyle Laboratories in the mid and late 70s. Much of this research was related to the identification of causes of accidents. The Wyle reports contained valuable information with regard to possible effects of environmental stressors on human response, and a variety of human factors issues. This research also addressed possible effects of current boat designs and their potential contributions to certain accident types. Excellent material is contained in many of the reports listed below regarding general accident investigation techniques on a variety of accident types, including collisions. Little material was devoted to collision accident reconstruction based on physical evidence, which is one of the main focuses of this report. The reports of the Wyle research projects are listed below.

1. Recreational Boat Safety Collision Research: Phase II, Report No. CG-D-128-76, R. Macneill, S. Cohen, Wyle Laboratories, 1976.

2. Pleasure Boat Collision Education: Final Report / Prepared for the USCG, Office of Research and Development, Report No. CG-D-51-78, Wyle Laboratories, May 1978.

3. Collision Accident Investigations For 1977 Season, Final Report, Report No. CG-D-61-78, J.J. Davis and Associates, April 1978.

4. Recreational Boat Safety Collision Research, Phase I Volume I: Problems Definition, Report No. CG-D-143-75, R. Macneill, et al, Wyle Laboratories, September 1975.

5. Recreational Boat Safety Collision Research: Collision Accident Investigations July 1976-Dec 76, Report No. CG-D-40-77, Wyle Laboratories, January 1977.

6. Boat Accident Investigation Seminar Proceedings, Final Report, Report No. CG-D-145-75, Wyle Laboratories, July 1975.

CHAPTER 2

ARE COLLISION ACCIDENTS SIGNIFICANT?

Part 1 - Accident Trends Based on Fatalities
Part 2 - Accident Trends Based on Other Data

Part 1

2.0 Introduction

In this section we are going to evaluate just how important collision accidents are in the broad overall area of boating accidents, especially when compared to the number of accidents of other major accident types. We are going to try to answer many of the questions under Goal No. 1 in Chapter 1.

2.1 The USCG Annual Statistics

Each year, the United States Coast Guard publishes a report titled "Boating Statistics," which summarizes accidents involving recreational boats. The USCG estimates that they receive reports of only 10% of all non-fatal accidents. However, they estimate that they receive reports of nearly all fatal accidents. For the purposes of our investigation, we will analyze the statistics for the twenty year period from 1970-1989.

A primary source of these statistics is from Boating Accident Reports submitted by individuals involved in an accident. While the submission of the report is required by law for reportable accidents, many operators are still unaware of the requirements for reporting boating accidents, or fail to report accidents for other reasons. As a result, it is difficult to obtain an accurate assessment of the boating accident situation from the USCG statistics. The statistics are however, the best information currently available on recreational boating accidents in the U.S. Based on the assumption that the USCG receives reports of nearly all of the accidents involving fatalities, the use of statistics concerning fatalities can be used to investigate the relative significance of various accident types. The use of statistics concerning non-fatal accidents can be considered to show interesting trends and general information; however, the results must be viewed with guarded caution as to their real accuracy.

In this section, we will first look at the significance of collisions primarily based on fatalities, since the USCG feels that nearly all fatalities are reported. This should provide the most accurate information available. Numbers of fatalities however, do not tell the entire story of accident trends. Therefore, we will also analyze the statistics using other criteria besides number of fatalities.

It is important to remember what constitutes a reportable boating accident. The following statement is taken from the Introduction to the USCG Boating Statistics, 1989.

> "Current regulations (33 CFR 173-4) require that the operator of any vessel that is numbered or used for recreational purposes file a report if the vessel is involved in an accident that results in:
>
> 1. Loss of life; or
> 2. Personal injury which required medical treatment beyond first aid; or
> 3. Damage to the vessel and other property exceeding $500.00; or
> 4. Complete loss of the vessel."

The USCG classifies collision accidents into three categories. The categories are collision with another vessel, collision with a fixed object, and collision with a floating object. For the purposes of determining the overall significance of collision accidents when compared to other accident types, the sum total of each of the three collision accident types have been added together and referred to simply as collision accidents or collisions. In order to determine the significance of collision accidents as a whole, the statistics on collisions have been compared to other major accident types. The two categories of accidents which generally account for the greatest number of fatalities each year are capsizing and falls overboard.

2.2 Decreasing Fatality Rates

In order to understand how collision accidents fit into the boating accident puzzle, it is necessary to spend some time analyzing the USCG statistics as a whole. Each year the USCG calculates the fatality rate per 100,000 boats based on the number of fatalities and the number of estimated boats in the United States. Except for 1985, this fatality rate has declined each year since 1973, in spite of the increase in the number of boats. In 1989, only 896 fatalities were recorded in all of recreational boating in the U.S. With such low fatality rates, one may wonder why even bother with studying accidents at all anymore. Some would ask the question, "Is it not obvious that boats are getting safer since the fatality rate is decreasing?" The answer to that question is extremely complex, but we believe we have some answers.

2.3 How Many Boats Are There Anyway?

The number of boats in the U.S. is indeed difficult to determine. It is a safe bet that no one knows exactly. Each year the USCG lists the "numbered" boats in the U.S. as reported by each state.

The number of boats that the USCG estimates are in the U.S. is always significantly greater than the numbered boats. Let it suffice to say that there are reasons for the greater number of estimated boats than numbered boats, but note that the fatality rate is based on the estimated number of boats. Figure 2-1 shows the number of estimated and numbered boats for each year since 1970. It is interesting to note that the difference between the numbered and estimated boats grows increasingly wider each year. Figure 2-2 shows the fatality rate based on both the numbered and estimated number of boats. Since the numbered boats are less than the estimated boats, the fatality rate per 100,000 boats is higher based on that figure. The real fatality rate may lie somewhere in between.

Regardless of the exact number of boats in the U.S. today, it is fairly certain that the number of boats has been increasing steadily for a long time. It is only natural to wonder how the accident rates for various accident types have been changing as a result of increasing numbers of boats on the nation's waters.

2.4 Fatalities for Various Accident Types

Since there is no way to be certain as to the number of boats in the U.S., fatality rate is perhaps not as important as the total number of fatalities each year. The total number of fatalities has generally declined over the last 20 years. Since the number of fatalities has been basically declining overall, the question arises as to whether fatalities in each category of accident (falls overboard, capsizing, etc) have also decreased. In order to gain some perspective on trends in collision accident rates with regard to other accident types, statistics for the other two major killer categories have also been analyzed. The category with the most fatalities has consistently been capsizings, followed by falls overboard, and then by collisions (with all three collision categories added together). Figure 2-3 plots the number of fatalities over the period studied for capsizings, falls overboard, and collisions.

The graphs in Figure 2-3 clearly illustrates the trends for the three main accident categories over the last 20 years. The number of fatalities due to capsizing has decreased dramatically. The number of fatalities due to falls overboard has generally decreased over the years, but not as dramatically as fatalities from capsizings. The number of fatalities from collision accidents has remained remarkably stable at around 180-200 each year. The significant item to note here is that while the number of fatalities from the other categories is decreasing, the number of fatalities from collisions has not significantly decreased at all.

Since we have looked at fatalities from only three accident types, one may wonder where the other accident categories would fit into the diagram. What other accident types are there? Figure 2-4

answers this question and is taken from the 1989 Boating Statistics. It lists the accident types as well as the vessels and fatalities for each category for 1989.

Capsizings, falls overboard, and collisions are the three categories with the most fatalities. If we took the total number of fatalities from the remaining accident categories and compared them to the big three, we could see the relative importance of the two groups of accidents. This is exactly what Figure 2-5 shows us with the total of the other accidents labeled "All Others." This graph is exactly like Figure 2-3 except that the total number of fatalities from all other accidents is now included. We can see that about the same number of fatalities have been occurring due to "All Others" as for falls overboard. Perhaps a clearer illustration of this same information is found in Figure 2-6 which shows that collisions, falls overboard, and capsizings have accounted for about 75% of all fatalities for the period studied. Conversely, all the other accident categories combined account only for about 25% of the fatalities. It is especially interesting to note that there is little deviation from the 75% figure for the last 20 years. Table 2-1 provides a summary of data that shows the percentage of fatalities each year which were caused by collision accidents. The table shows that even in the worst year between 1970 and 1989 that collisions only accounted for 17.7% of the total fatalities.

2.5 Good News and Bad News

The good news that comes from this analysis is obviously that in spite of increasing numbers of boats, the total number of fatalities has been generally decreasing. It is important to look briefly at the trends for each accident type in order to gain some insight into future accident trends. Figure 2-7 is an area graph which shows the number of fatalities for the three major categories, and "All Others." The totals for each group here are additive, so the top line represents the total number of fatalities for each year. This figure shows how slight decreases in each of the accident types can result in a much more significant decrease in the total.

The bad news is that Figure 2-7 also shows that the number of fatalities from collisions has not decreased at all. Based on these figures, what can be said about future accident trends?

We cannot really answer that question yet because we do not have the whole story. The accident trends based on fatalities may be the most accurate of the USCG statistics, but they paint what may be a totally unrealistic picture of optimism about the future. In order to gain a better understanding of the accident trends overall, we need to consider other data available.

Part 2 - Accident Trends Based On Other Data

2.6 Introduction

In Part 1 of this chapter we analyzed the data on accident trends based on the number of fatalities. Now we want to look at accident rates based on other information available. This information includes number of accidents, and number of vessels involved. Hopefully we can obtain a more balanced picture by considering all of the data available.

2.7 Analysis Based on Number of Accidents

It only seems logical that as the number of boats increases that the number of accidents and fatalities would increase as well. However, in Part 1, we saw that the number of fatalities has definitely been decreasing. But what about the number of accidents? If we plot the number of accidents for each accident type, we see that logic once again fails us. Figure 2-8 shows the number of accidents for the three major accident types. The number of accidents for falls overboard has stayed about the same. The trend for the number of accidents involving capsizings has been fairly flat, with perhaps a slight decrease over the period. This is not exactly what one may have expected. However, the number of reported collision accidents has increased dramatically. In fact it has approximately doubled since 1970.

Once again, we may wonder where all the other accident types fit in. Figure 2-9 shows the three major accident types with "All Others" added to the graph. Remember that "All Others" represents the sum of all accidents other than capsizings, falls overboard, and the three collision categories. We see from Figure 2-9 that there has been a general increase in these categories as a whole since 1970.

In terms of number of accidents, capsizes and falls overboard account for only a small portion of the total number of accidents reported each year, while collisions account for the largest percentage. Figure 2-10 shows the relative percentage for which each accident type accounts. From this graph, it is obvious that falls overboard and capsizing are a small percentage of the total number of accidents. Figure 2-11 plots the actual percentage of each accident type in terms of number of accidents. Here it can be seen that falls overboard has consistently accounted for about eight to ten percent of the number of accidents, while capsizing has declined from around 15 to 16% in 1970 to less than 10 percent in 1989. The "All Others" category has remained at 32 to 35%. The dramatic difference has been that collision accidents have increased from about 42% to about 52% for the last few years plotted.

2.8 Analysis Based on Number of Vessels

Let's take a brief look at the number of vessels involved in accidents. For this section, we will look specifically at vessels involved in collision accidents. A comparison of the number of vessels involved with falls overboard and capsizings was done and yielded results very similar to graphs already discussed for number of accidents. This is because you can generally count on one boat involved per accident for falls overboard and capsizing.

The total number of vessels involved in collision accidents each year is quite staggering. The graphs in Figure 2-12 show the total number of vessels involved each year in all accidents and the number of vessels involved in collision accidents. Two things are evident from this graph. One is that the number of vessels involved in collisions is almost directly proportional to the total vessels involved in all accidents. The second is that collisions account for over half of the vessels involved in an accident. Figure 2-13 shows just how much of the accident total in terms of number of vessels is due to collision accidents. In 1970, approximately 53% of the vessels involved in an accident were in a collision accident. By 1988, the number had increased to 65%.

There are two general conclusions that are indicated by analyzing the number of vessels involved in accidents. The first is that the number of vessels that are involved in accidents each year has generally increased, as has the number of boats. The second is that the percentage of vessels involved in collision accidents has increased. The latter is primarily because the number of accidents for falls overboard and capsizings has decreased. We must also remember to be cautious when studying statistics not related to fatalities derived from the USCG, as their true accuracy is unknown.

2.9 Accidents as a Function of an Increasing Boat Population

Thus far we have looked at accident statistics each year based on number of fatalities, number of vessels, and number of accidents for each accident type. We would like to know what to expect in the future concerning the major accident types. One way to get a handle on this question is to look at statistics in terms of numbers of boats. Figure 2-14 shows a plot of the number of vessels involved in accidents versus the estimated number of boats. In 1988, the number of vessels involved in accidents was about 9000. If the USCG is correct in that they only receive reports of 10% of non-fatal accidents, then as many as 90,000 vessels may have been in an accident in 1988. This translates into an accident rate of 500 accidents per 100,000 boats (based on an estimated 18 million boats). The fatality rate for 1988 was published as 5.1 fatalities per 100,000 boats. The implication of these figures is that the accident rate and possibly the injury rate is 100 times greater than the published fatality rate.

The only figures we can use with any certainty are those involving fatalities. Twenty years ago, probably no one would have predicted that the total number of annual fatalities would decrease like it has, especially when considering the dramatic increase in the number of boats. Figure 2-15 shows how the number of fatalities has changed as the boat population has increased. The top line on the graph illustrates the dramatic decrease in deaths in spite of the increasing number of boats. The second line represents a significant decrease in deaths due to capsizing. The number of deaths due to falls overboard and collisions has remained fairly constant when viewed as a function of the number of boats.

It is of course difficult to predict what the future holds. Figure 2-16 may be the best indicator of future trends. This figure shows the role that each accident type plays in the total number of fatalities. Deaths due to capsizing have accounted for about 35% of the fatalities since 1982. Deaths from falls overboard and all others remained fairly consistent and have accounted for about 25% each of the total. Collisions in 1970 only accounted for 10% of the fatalities, and have accounted for as much as 18% in recent years.

Of special significance to this investigation is that collision accidents are likely to account for a greater percentage of the deaths each year for as long as the boat population increases. This would not necessarily be bad news if the only reason was the decreasing number of deaths from other accident types. However, the number of collision accidents, and the number of deaths, may begin to increase as the waterways become more crowded.

2.10 Analysis

The number of accidents and fatalities due to capsizings has possibly decreased because of legislation requiring proper flotation in boats and boater education. Boater education and regulations requiring the availability of PFDs on board vessels may also have contributed to the continued decline in accidents and fatalities from falls overboard. Boating accidents in general may decrease during times of economic stress, since boating can be a significant a recreational expense.

But what about collisions? What actions have been taken to account for the fact that the number of fatalities has not increased? More and more states have enacted speed limit laws and placed increased emphasis on boater education. This has probably had a tremendous effect on holding down the number of fatalities. Also, many states have enacted legislation to remove the drunk boater from the waterways. This has no doubt had an impact. To date however, there have been no regulations that affect the degree of occupant protection that a boat must provide. Even so, many boat manufacturers have begun voluntarily to consider occupant protection issues in the design and construction of their boats.

It is unfortunate that additional data is not available on the number of collision accidents. It is unlikely that the USCG statistics, which show an increase in the number of collision accidents, would be proven incorrect.

Perhaps the most unique characteristic about collision accidents is that, as waterways become more congested, this category of accidents may be the toughest to keep under control. While many other accident types can be battled with boater education and new legislation, collision accidents will probably not be dealt with so easily. The likelihood of a particular boat being involved in a collision accident is, to a large extent, proportional to the congestion of the water on which that boat is used. No other accident type has this unique characteristic. The implication is that as the boating population increases, the number of collision accidents will too.

Collisions will also be hard to deal with because they are accidents of chance. As far as we can tell relatively few collision accidents are directly caused by mechanical failure. They will typically involve some element of human error. A split second decision will often decide between life and death. No amount of boater education, improvements in boat construction, or changes in legislation will eliminate all collision accidents. The real question of the future is, "Will anyone take action to minimize the number of collision accidents and the resulting injuries and fatalities which will occur each year?"

2.11 Conclusions - What About the Future?

Based on the information in this chapter, we can make the following statements about future accidents trends concerning collision accidents as a whole:

a. The number of collision accidents will probably continue to increase in direct proportion to the number of boats. The number of fatalities due to collisions will start to increase unless specific efforts are continued which work against the effects of increasing congestion of the waterways.

b. The number of fatalities from capsizings and falls overboard will not continue to decline indefinitely. At some point, the number of accidents and number of fatalities associated therewith is likely to stabilize or increase again.

c. Capsizings, falls overboard, and collisions combined will probably continue to account for about 75% of the fatalities on the nation's waterways, with an increasing percentage being attributed to collisions.

Collision Fatality Summary Data

Year	Total Fatalities	Total Collisions Fatalities	Collision Fatalities % of Total
70	1418	142	10.0%
71	1582	164	10.4%
72	1437	156	10.9%
73	1784	153	8.6%
74	1446	143	9.9%
75	1466	158	10.8%
76	1264	151	11.9%
77	1312	177	13.5%
78	1321	187	14.2%
79	1400	218	15.6%
80	1360	184	13.5%
81	1208	149	12.3%
82	1178	179	15.2%
83	1241	207	16.7%
84	1063	161	15.1%
85	1116	199	17.8%
86	1066	173	16.2%
87	1033	155	15.0%
88	946	167	17.7%
89	896	128	14.3%
Summary:			
Total:	25537	3351	
Average:	1277	168	13.5%

Notes:

Total Fatalities = Total number of fatalities for all accidents
Collisions Total = Total number of fatalities for collision accidents only
Collisions % of Total = The percentage of fatalities that were caused by a collision type accident
For Summary Data: Total is the total for the 20 year period
Average is the average number for each year

Table 2-1

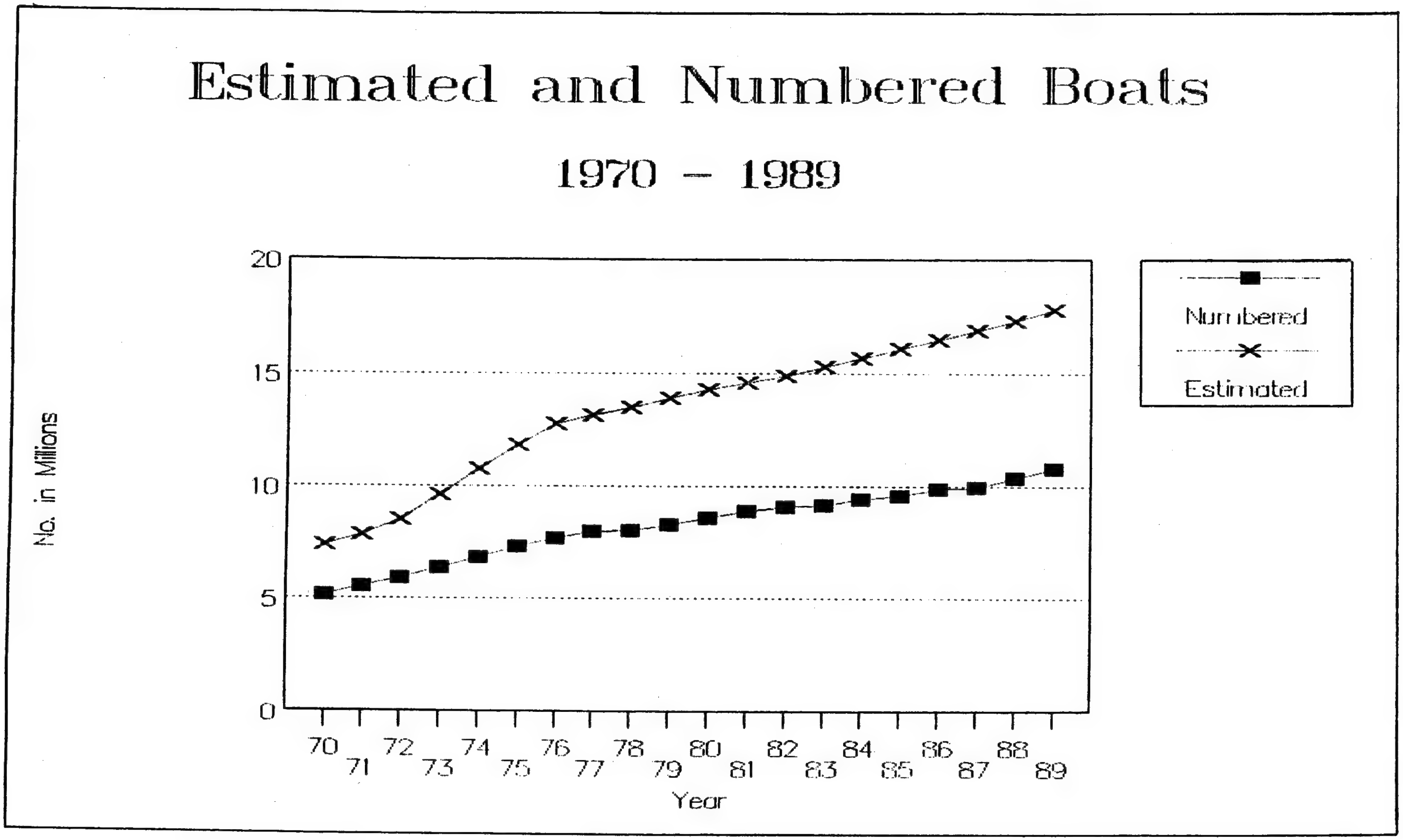
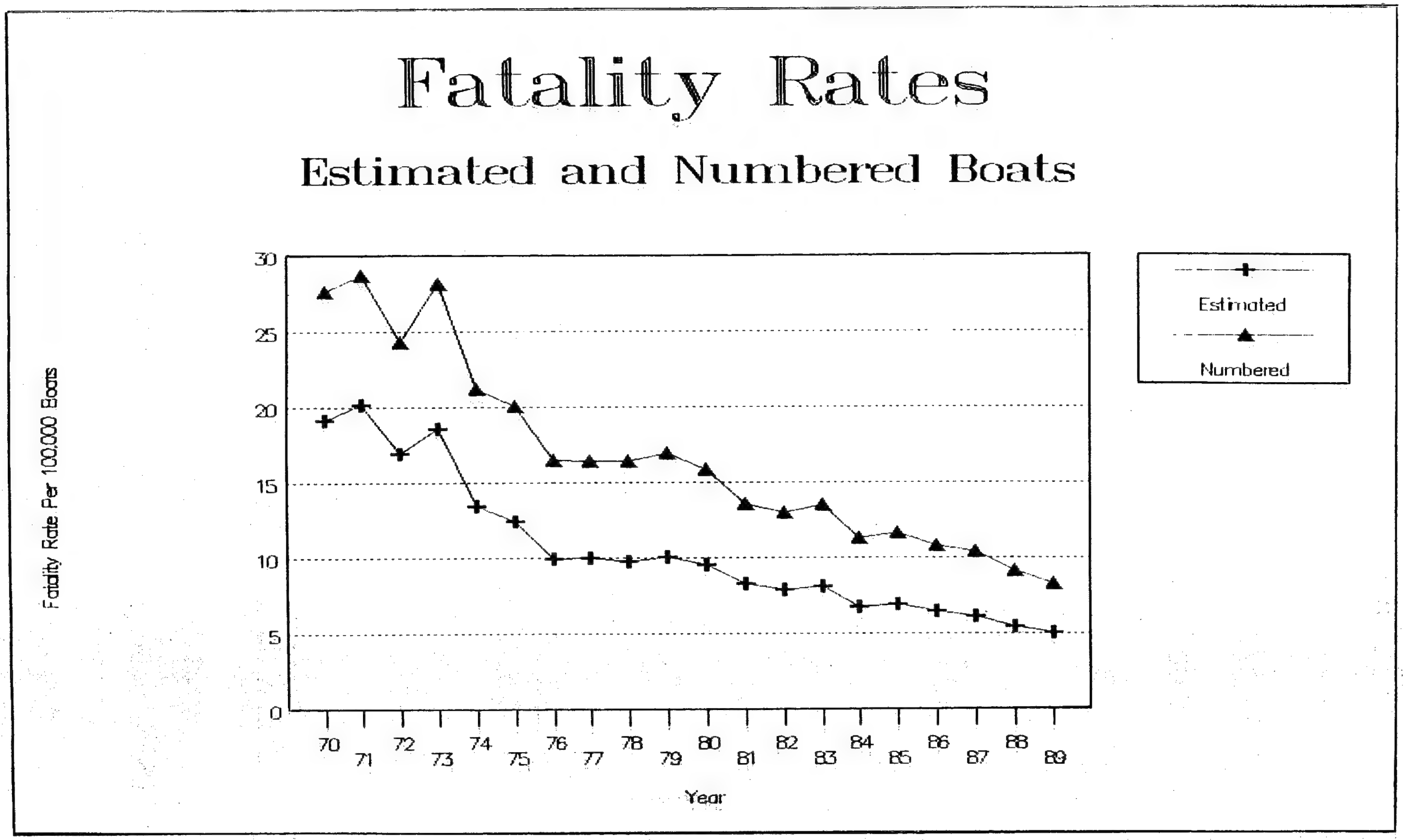

Estimated and Numbered Boats
1970 – 1989
No. in Millions
20
15
10
5
0
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Numbered
Estimated

Figure 2-1



Fatality Rates
Estimated and Numbered Boats
Fatality Rate Per 100,000 Boats
30
25
20
15
10
5
0
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Estimated
Numbered

Figure 2-2

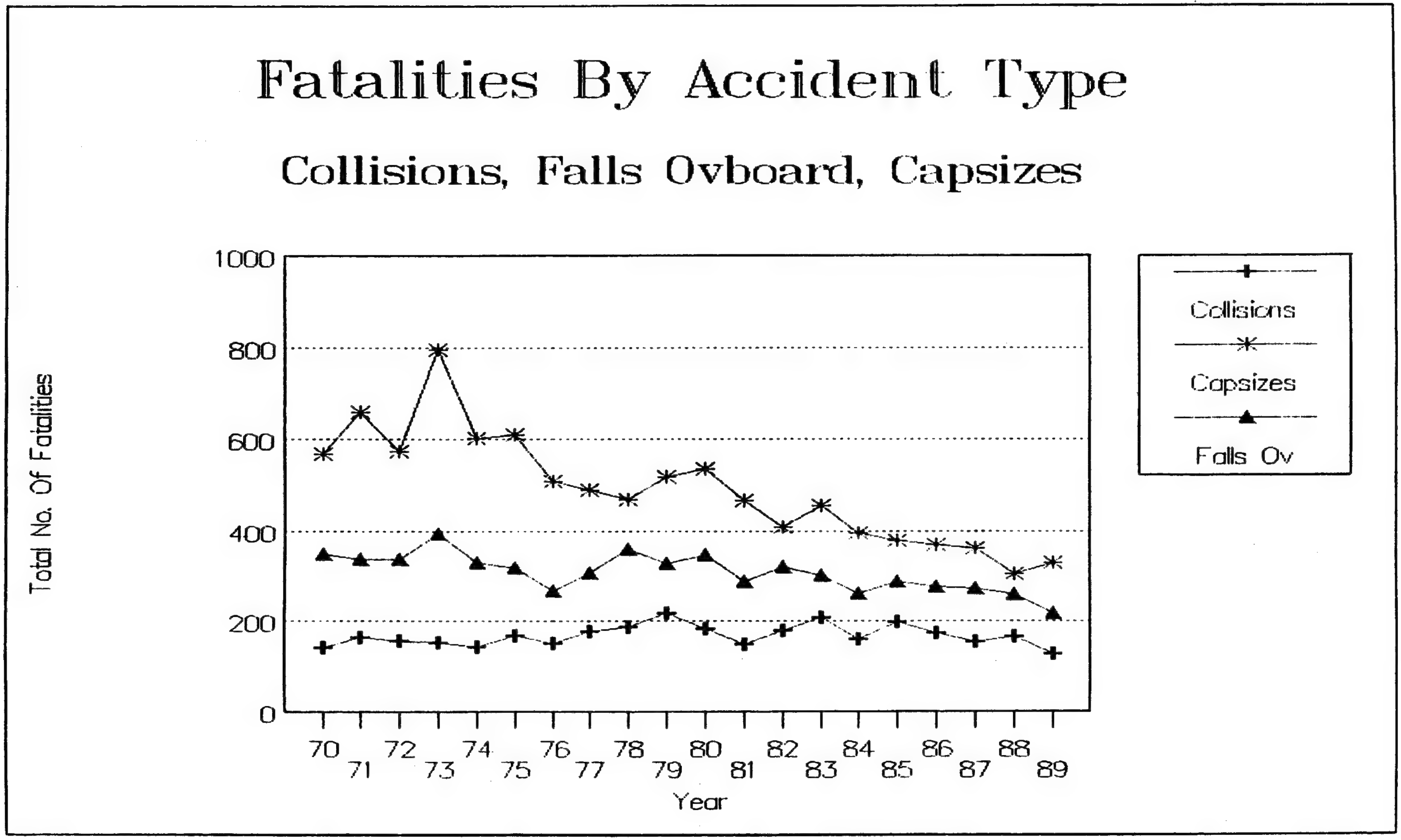

Fatalities By Accident Type
Collisions, Falls Ovboard, Capsizes
Total No. Of Fatalities
1000
800
600
400
200
0
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Collisions
Capsizes
Falls Ov

Figure 2-3

TYPES OF BOATING ACCIDENTS 1989

	VESSELS INVOLVED	FATALITIES
TOTALS	8,020	896
Grounding	386	13
Capsizing	576	330
Swamping/Flooding	228	70
Sinking	219	31
Fire/Explosion (fuel)	303	7
Fire/Explosion (other)	60	6
Collision with another vessel	3,995	60
Collision with fixed object	797	60
Collision with floating object	296	8
Falls overboard	428	217
Falls within boat	119	0
Struck by boat or propeller	65	6
Other	517	47
Unknown	31	41

Type of accident refers only to the first event that occurred. Some accidents involve more than one event (e.g., a grounding followed by a sinking is included here only as a grounding even though the sinking may have led directly to a drowning fatality).

We estimate that we receive reports for approximately 10 percent of all non-fatal accidents.

Figure 2-4

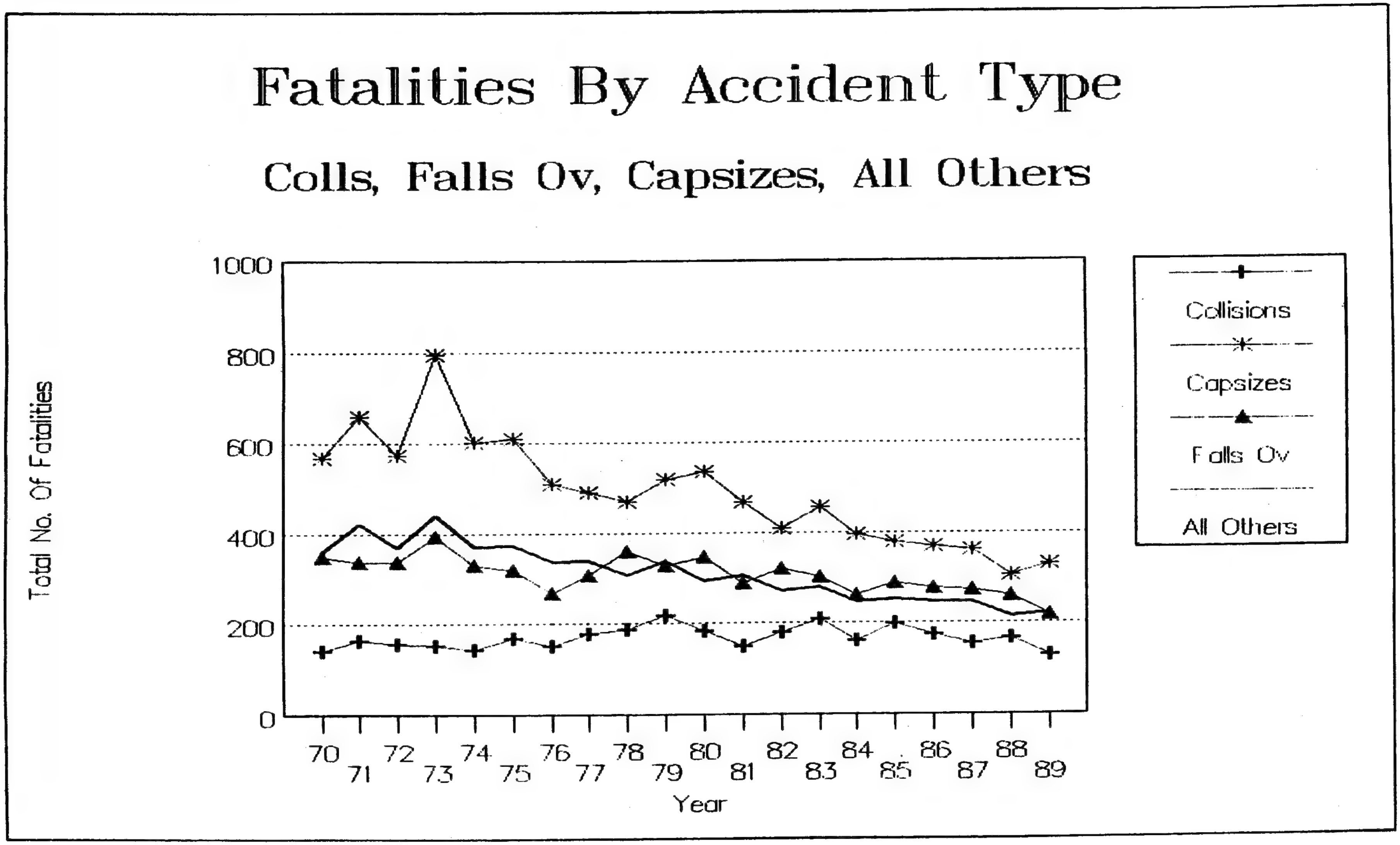

Fatalities By Accident Type
Colls, Falls Ov, Capsizes, All Others
Total No. Of Fatalities
0
200
400
600
800
1000
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Collisions
Capsizes
Falls Ov
All Others

Figure 2-5

No. Of Fatalities by Accident Type

Expressed in Percent of Total

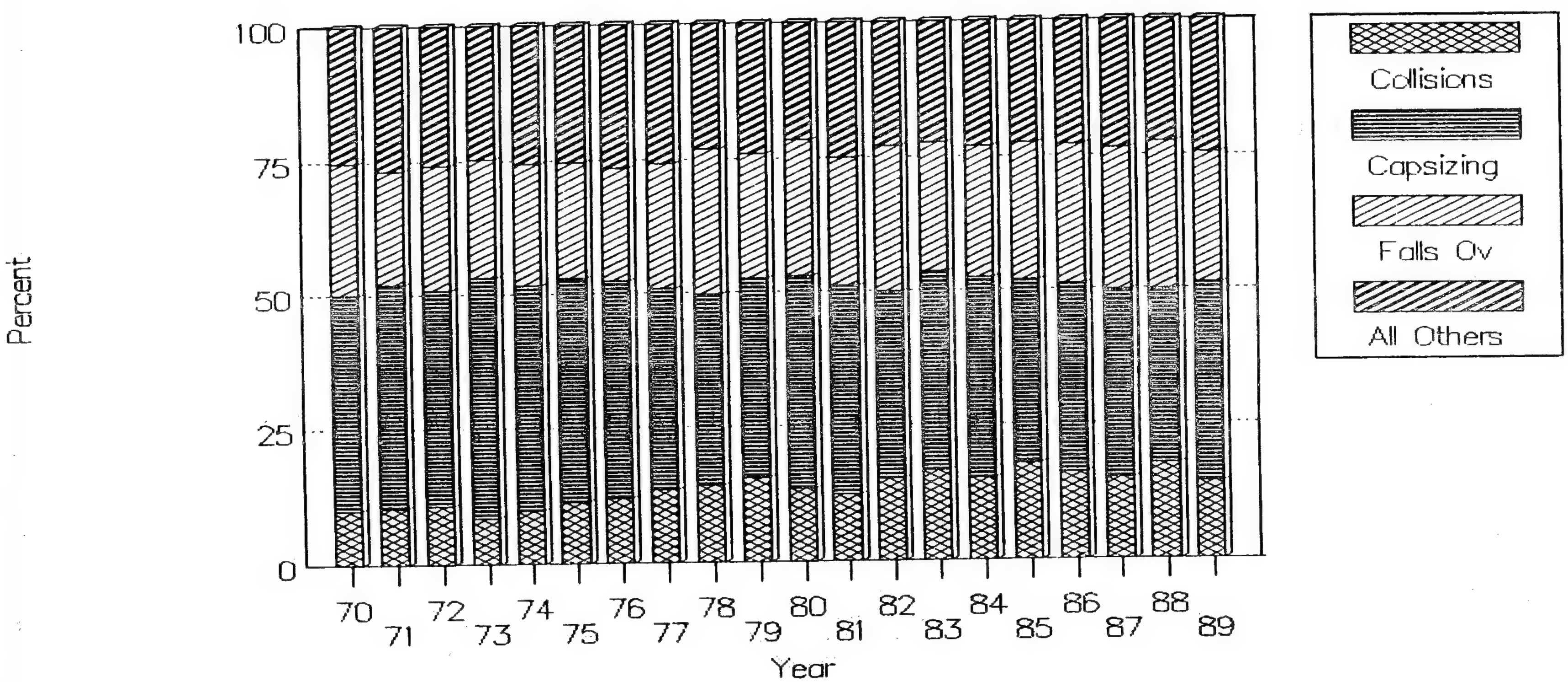


Figure 2-6

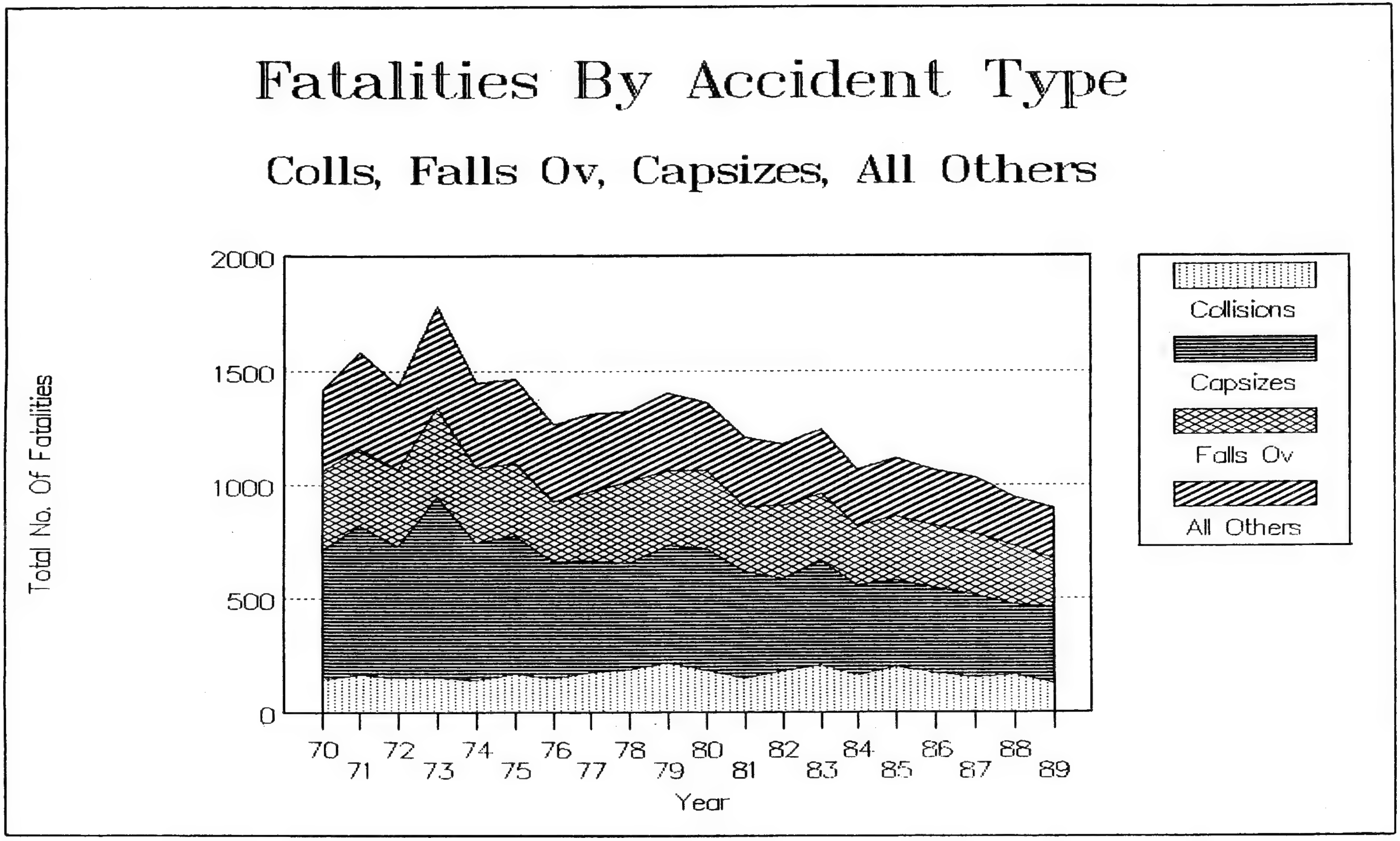

Fatalities By Accident Type
Colls, Falls Ov, Capsizes, All Others
Total No. Of Fatalities
2000
1500
1000
500
0
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89
Year
Collisions
Capsizes
Falls Ov
All Others

Figure 2-7

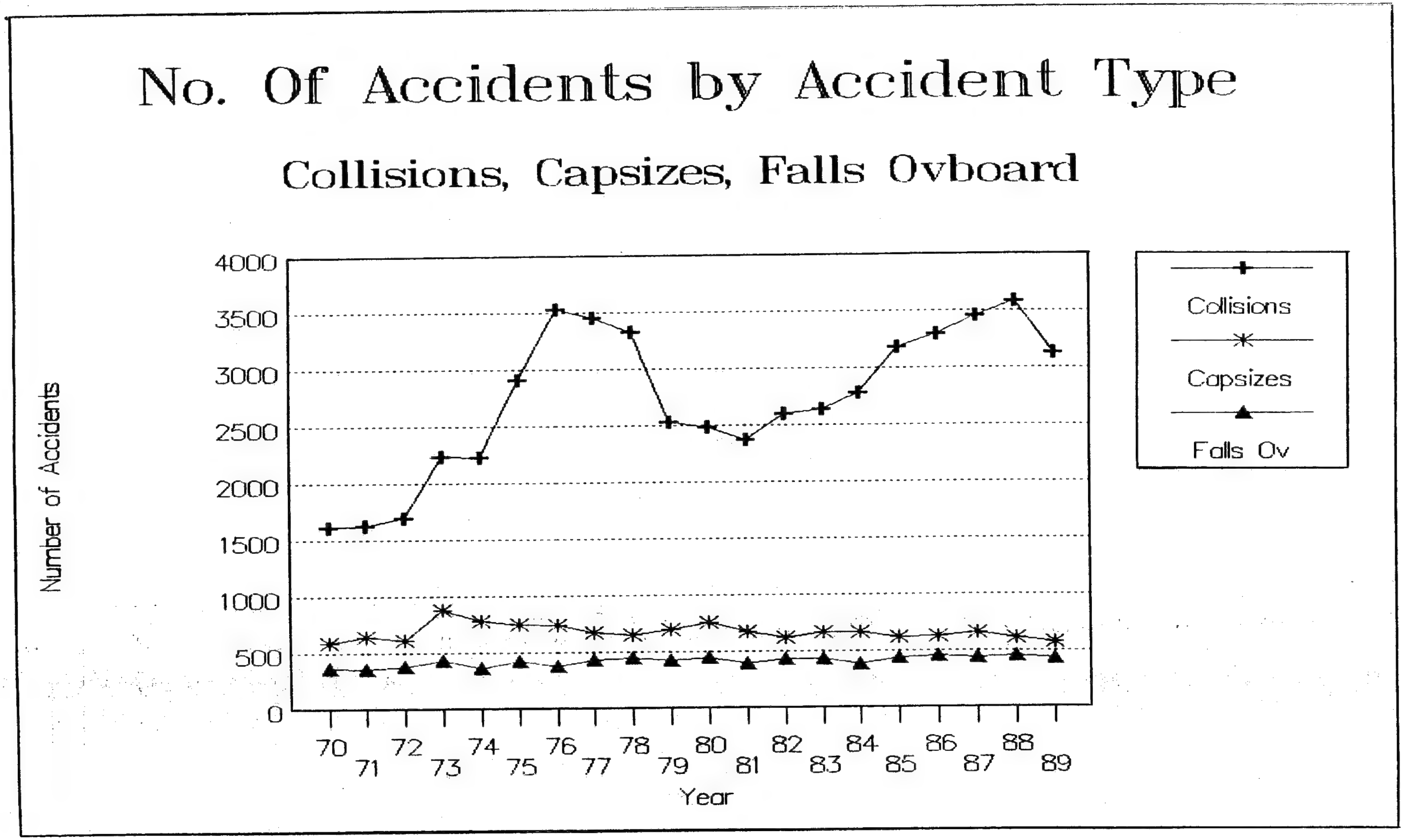
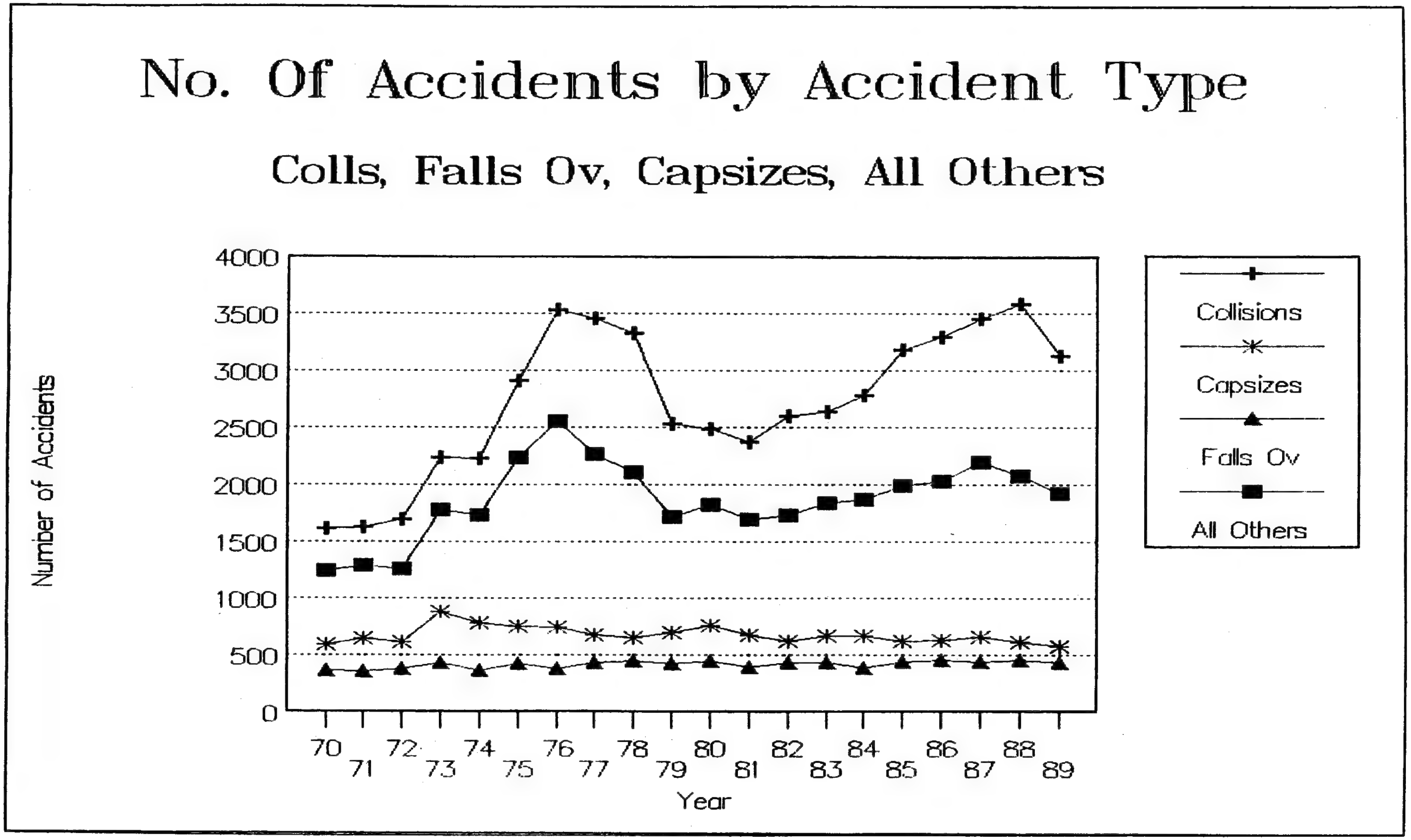

No. Of Accidents by Accident Type
Collisions, Capsizes, Falls Ovboard
Number of Accidents
4000
3500
3000
2500
2000
1500
1000
500
0
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89
Year
Collisions
Capsizes
Falls Ov

Figure 2-8



No. Of Accidents by Accident Type
Colls, Falls Ov, Capsizes, All Others
Number of Accidents
4000
3500
3000
2500
2000
1500
1000
500
0
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89
Year
Collisions
Capsizes
Falls Ov
All Others

Figure 2-9

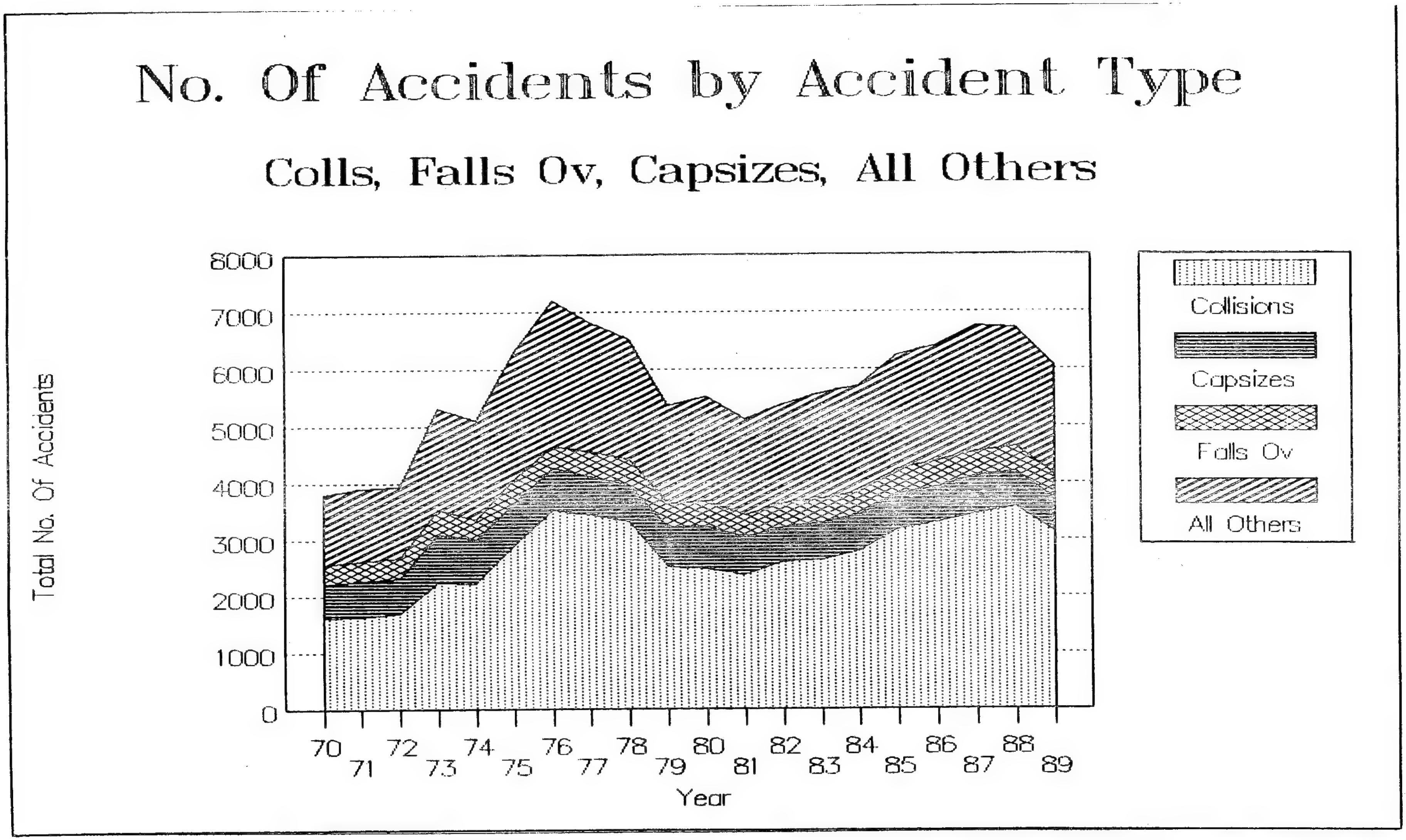

No. Of Accidents by Accident Type
Colls, Falls Ov, Capsizes, All Others
Total No. Of Accidents
8000
7000
6000
5000
4000
3000
2000
1000
0
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89
Year
Collisions
Capsizes
Falls Ov
All Others

Figure 2-10

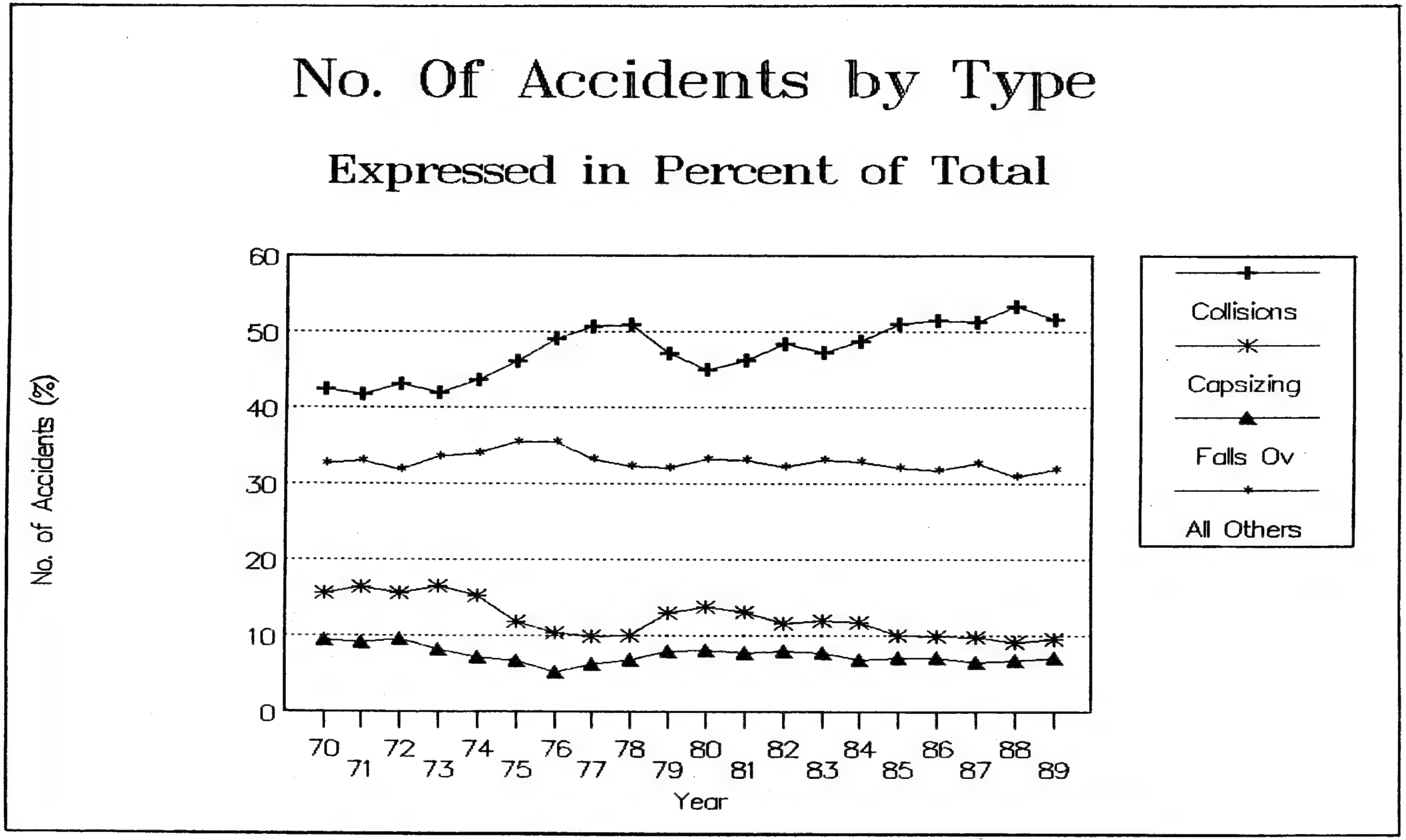

No. Of Accidents by Type
Expressed in Percent of Total
No. of Accidents (%)
0
10
20
30
40
50
60
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Collisions
Capsizing
Falls Ov
All Others

Figure 2-11

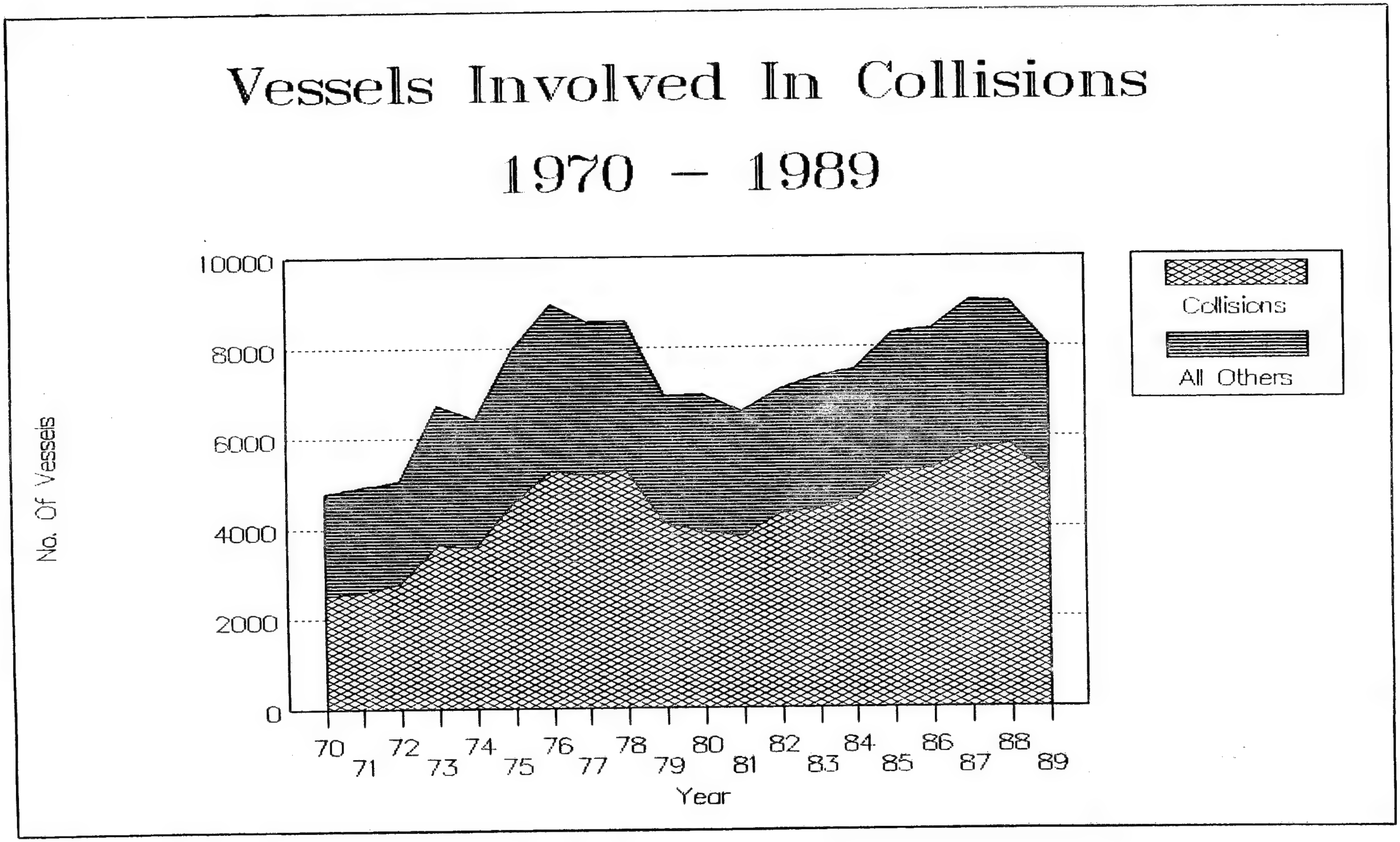

Vessels Involved In Collisions
1970 – 1989
No. Of Vessels
10000
8000
6000
4000
2000
0
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89
Year
Collisions
All Others

Figure 2-12

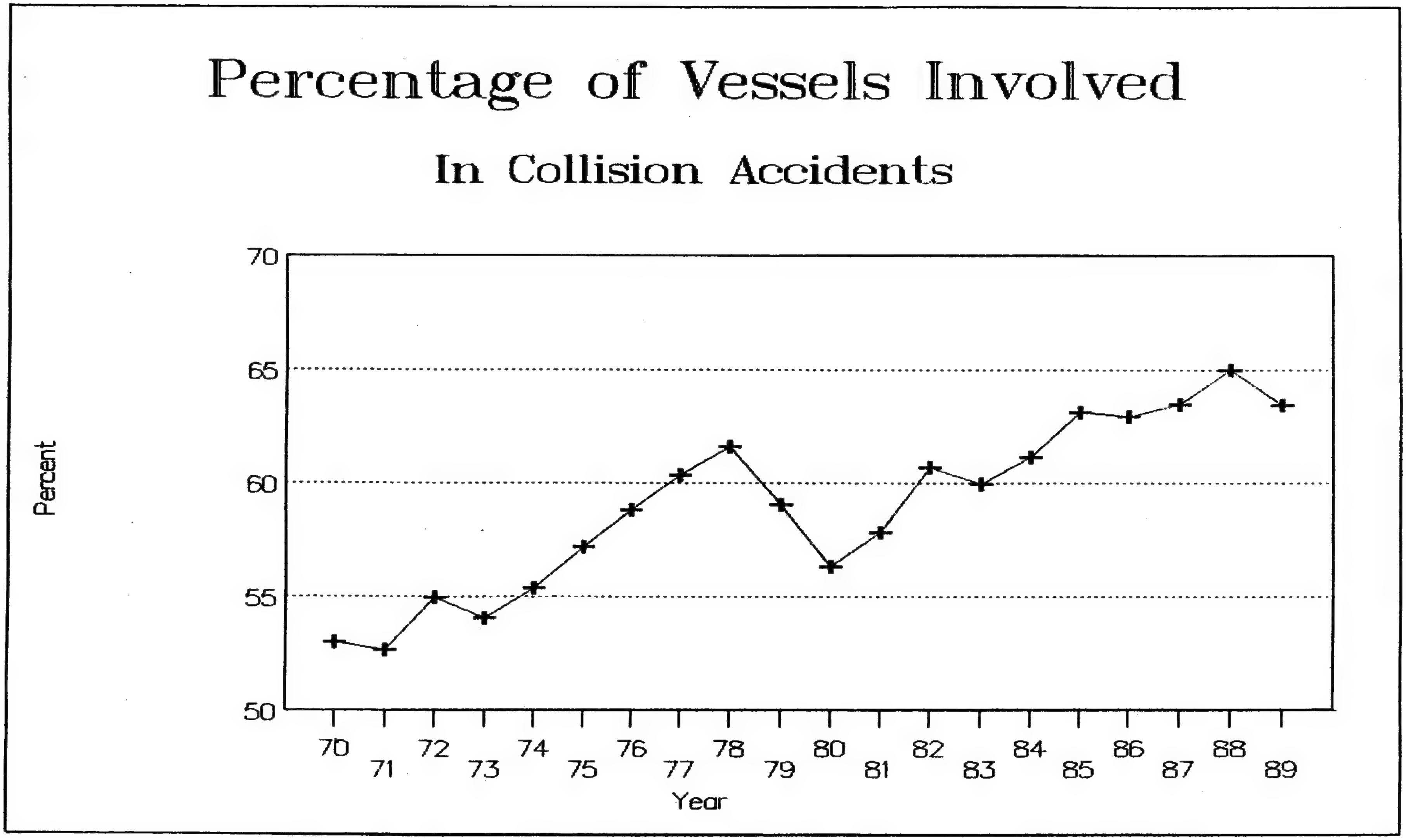

Percentage of Vessels Involved
In Collision Accidents
Percent
70
65
60
55
50
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89
Year

Figure 2-13

No. Vessels in Accidents vs. Estimated No. of Boats

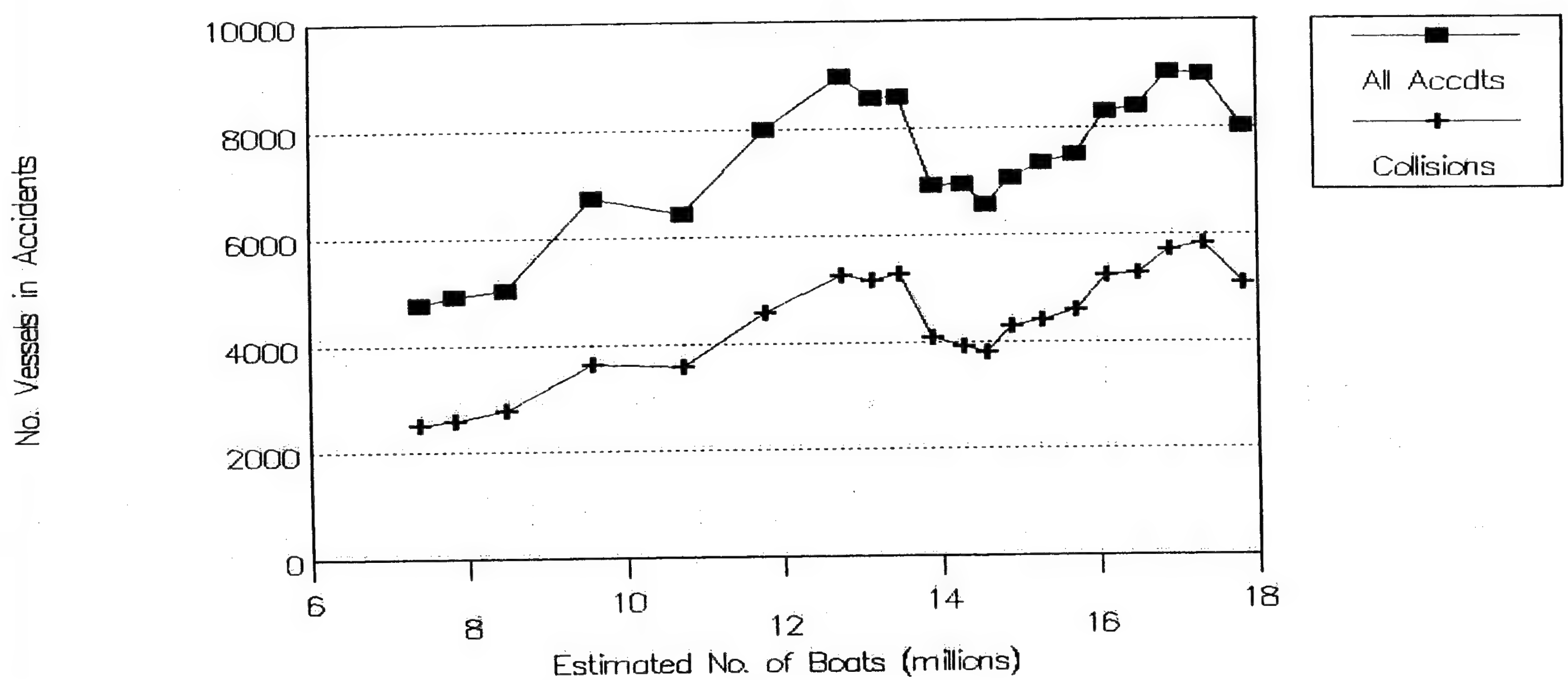


Figure 2-14

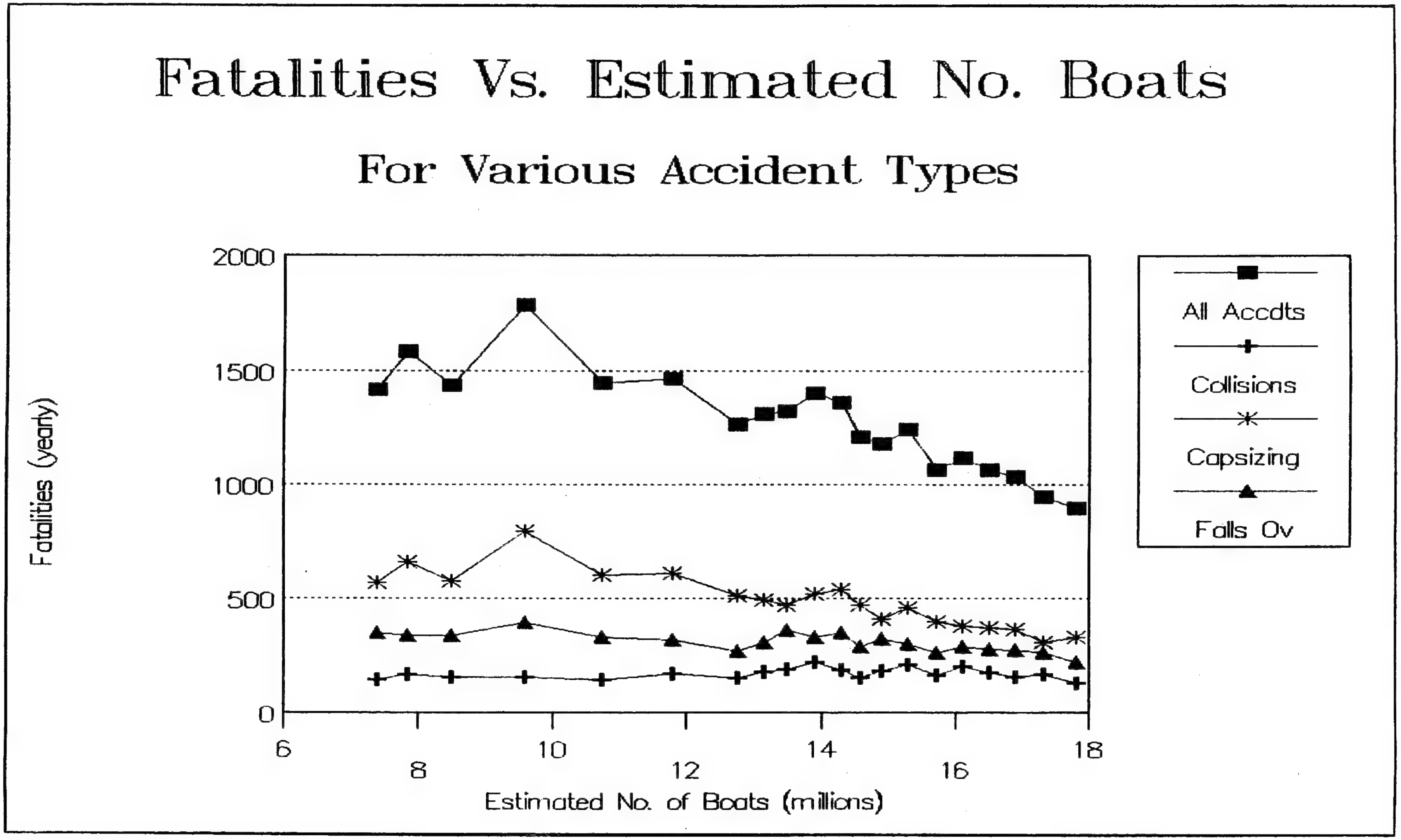
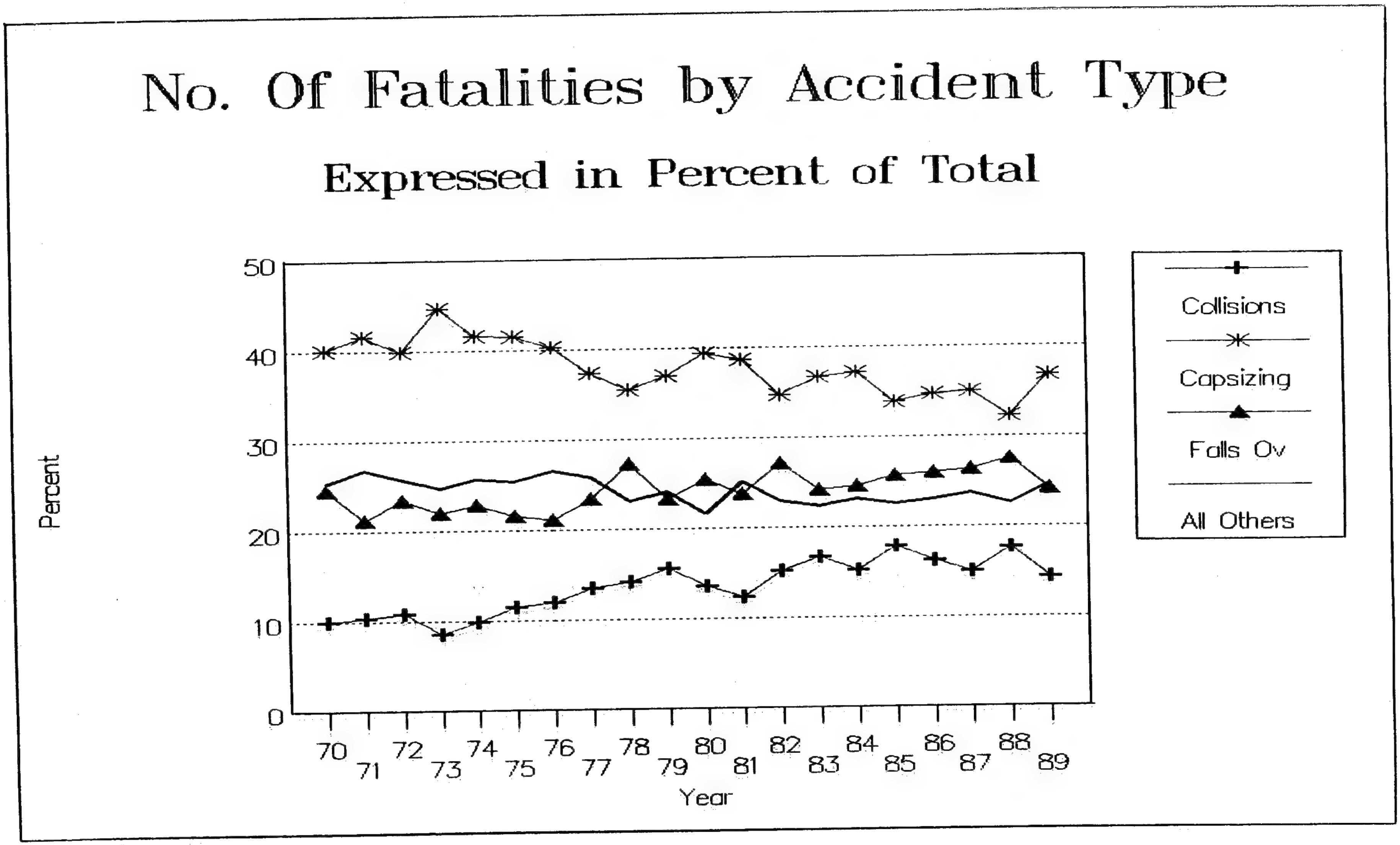

Fatalities Vs. Estimated No. Boats
For Various Accident Types
Fatalities (yearly)
2000
1500
1000
500
0
6
8
10
12
14
16
18
Estimated No. of Boats (millions)
All Accdts
Collisions
Capsizing
Falls Ov

Figure 2-15



No. Of Fatalities by Accident Type
Expressed in Percent of Total
Percent
50
40
30
20
10
0
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Collisions
Capsizing
Falls Ov
All Others

Figure 2-16

CHAPTER 3

DETAILED STUDY OF COLLISION TYPE ACCIDENTS

PART 1 - Collision Accidents Trends Based on Fatalities
PART 2 - Collision Accidents Based on Other Data

PART 1

3.1 Introduction

In the last chapter, we examined the significance of collision accidents overall when compared to other types of accidents. Now we want to look at collision accidents in more detail. Collision accidents are classified by the United States Coast Guard into one of three categories. These categories are collisions with another vessel, collisions with a fixed object, or collisions with a floating object. By taking an in depth look at the number of fatalities in each category, and analyzing the trends from the period from 1970 through 1989, we may gain some insight into the importance of each of these accident types. Once again, the statistics for this chapter are taken from the USCG annual boating statistics. The primary emphasis for this chapter will be on statistics including fatalities, since these numbers are probably the most accurate. However, we will briefly look at other available data on numbers of accidents to obtain a broader perspective on the collision problem. The reliability of the statistics on numbers of accidents is however unknown, and any conclusions based on the statistics other than those involving fatalities must be viewed cautiously. Remember that the USCG estimates that they receive reports of only about 10% of non-fatal accidents.

3.2 Which Collision Accident Type Is The Most Deadly?

The answer to this question is not as simple as one might think. Figure 3-1 shows the number of fatalities for each type of collision accident for the last twenty years. The shaded areas represent the number of fatalities for each accident type. The categories are additive here, so the top line represents the total number of collision fatalities. Two conclusions become readily apparent from this graph. First, the number of fatalities due to collisions with another vessel is about the same as collisions with a fixed object. Second, collisions with floating objects do not contribute nearly as many fatalities as the other two collision accident types.

Exactly how many fatalities are contributed by each accident type? Part of the answer is found in Figure 3-2. This graph plots the number of fatalities for each accident type. For the time period analyzed, the data is too scattered to identify any dramatic

trends for the two major categories. The trends for one accident category do not appear to be consistent with any of the other categories. During some years when the fatalities for collisions with fixed objects increased, fatalities from collisions with another vessel decreased. It does appear that the number of fatalities due to collisions with floating objects has generally been decreasing for the 20 year period studied. A summary of specific figures regarding number of fatalities for each collision accident type are provided in Table 3-1.

The specific differences between the two accident types are better seen in Table 3.1. This table deals only with the three collision type accidents. The purpose of the table is to help us get a better grasp on the number of fatalities caused by each accident type. Since the graphs in Figure 3-1 and 3-2 show that the number of fatalities for both collisions with another vessel and collisions with a fixed object are fairly close, it is necessary to compare the numbers of fatalities for these categories in a tabular form to really answer the question of which category has claimed the most lives. Table 3-1 shows the total number of fatalities for each year and the percentage of the total collision fatalities for each category.

The summary data at the bottom of the table provides cumulative totals for the 20 year period and averages for each year. Note that collisions with a fixed object have resulted in the deaths of over 100 people more than collisions with another vessel. It is also interesting to note that for 11 out of 20 years, collisions with a fixed object has resulted in more fatalities than collisions with another vessel. For the remaining nine years, the opposite has been true, except for 1989 when the number of fatalities for the two categories was the same at 60. The average percentages for 1970 thru 1989 for each accident type show that 45.9% of the deaths from a collision type accident resulted from a collision with a fixed object, while 42.5% of the collision fatalities were from collisions with another vessel. Collisions with a floating object accounted for an average of 11.6% of the collision fatalities for the 20 year period. It is important to remember that the percentages given are in terms of total fatalities for collision accidents only, not fatalities for all of recreational boating. Remember from Chapter 2 that all three collision accident categories combined only accounted for 11.1% of the total number of boating fatalities for the last twenty years.

3.3 Collision Fatalities- In Percentages by Accident Type

To continue to gain a better understanding of how each collision accident type contributes to the collision problem as a whole, it is useful to look in more detail at the percentage of fatalities caused by each accident type. Figure 3-3 shows the percentage for each collision accident type for the period studied. This graph is a fairly clear representation of the average percentages calculated in Table 3-1. In other words, it is more

easily seen here that the line representing the fatalities from collisions with fixed objects is above the collision with another vessel line for most of the graph. This is consistent with earlier data which showed that collisions with fixed objects claimed the highest number of fatalities.

3.4 Analysis of Fatality Data

It is worthwhile to stop for a moment and think about what these numbers mean. Great attention has been given to collision accidents in general in the last few years and almost all of that attention solely to collisions with another vessel. From the fatality data it can be safely concluded that with regard to fatalities, collisions with fixed objects are an equally serious problem. However, before we offer a complete analysis of the data concerning the collision type accidents, we want to consider the other available data on collisions.

PART 2 - COLLISION ACCIDENT TRENDS BASED ON OTHER DATA

3.5 Introduction

Part 1 of this chapter concentrated on analysis of statistics based on fatalities. Fatality data is the most accurate, but it is of value to look at the other data available as well. While the numbers we will study in this part may not be a true indication of the number of accidents occurring in the field, they may give us an indication of the relative frequency of each accident type.

3.6 Number of Accidents

The USCG statistics concerning the number of accidents provide an interesting story of the relative frequency of the various collision accident types. The graphs in Figures 3-4 and 3-5 illustrate the numbers of accidents reported to the USCG for each collision accident type. Figure 3-4 shows that for the entire period studied, most of the collision accidents reported have been collisions with another vessel. It also shows that the number of accidents reported to the USCG has generally increased since 1970. The specific numbers of each accident type are shown in Figure 3-5. Note that the numbers of accidents in collisions with another vessel have risen fairly sharply, while the other accident types increased until about 1977, and then appear to have leveled off somewhat. Figure 3-6 and 3-7 illustrate that approximately 60 to 70% of the collision accidents are collisions with another vessel.

3.7 Number of Vessels Involved

Collision accidents are unique in that the number of accidents is nowhere near the same as the number of vessels involved. While there are occasions where another accident type will involve more than one vessel, such as a fire or explosion, it is not the normal occurrence. However, collision with another vessel is an accident type that automatically involves at least two vessels. For that reason, it is valuable to look at the number of vessels involved in collisions to understand the relative severity of each accident type. Figures 3-8 and 3-9 show the numbers of vessels involved, and the percentage of the total number of vessels for each accident type, respectively. These numbers separate the collision with another vessel accident type from the others like no other statistics will, accounting for approximately 80% of all vessels involved in a collision accident. By contrast, only around 5% of the vessels are involved in the collision with a floating object, and 15% in a collision with a fixed object.

3.8 Analysis

Collisions with another vessel account for more than 60% of all the collision accidents and approximately 80% of all the vessels involved. Collisions with fixed objects involve only about 15% of the vessels involved in collisions, yet account for more fatalities than collisions with another vessel. Collisions with floating objects are not a major contributor to numbers of accidents or number of fatalities when compared to other areas. Over a 20 year period, the average number of yearly fatalities from collisions with another vessel was 71, while it was 77 for collisions with a fixed object. Even though we must always keep in mind the unknown accuracy of the statistics involving nonfatal accidents, which includes the statistics we have used for numbers of accidents and numbers of vessels involved, we can be fairly certain that collision with another vessel is indeed a much more common accident than collision with a fixed object. The implication of the statistics is that a boater is from three to five times more likely to be involved in a collision with another vessel than a fixed object. Based on these statistics, a boater is five times more likely to be killed if he is in a collision with a fixed object than if he is in a collision with another vessel.

If better data were available on boating collision accidents, it would provide additional data to illustrate the severity of the collision problem. Officers who have attended the UL Boating Accident Investigation Seminars have generally felt that collisions with another vessel was their most common accident. While not all collisions result in a fatality, it is felt that nearly all of them result in some degree of injury to the occupants, especially to the occupants in the struck boat.

3.9 Collision Accident Types and Accident Reconstruction

There is little debate that of the three collision accident types, collisions with another vessel bring about the greatest difficulties for the accident investigator. They are the most frequently encountered accident types. Questions regarding who was at fault will arise because these collisions involve two operators, not just one. Due to the frequency of collisions with another vessel, it is important to learn as much as possible about these accident types. With regard to improving boating safety however, equal attention must be given to collisions with a fixed object since they account for approximately the same number of fatalities.

Collision Accident Fatality Breakdown - For Each Collision Accident Type

Total Facilities and Percentage of Total
(Totals) (Percent)

Year	Collisions With Another Vessel		Collisions With Fixed Object		Collision With Floating Object		All Collisions
	Totals	Percent	Totals	Percent	Totals	Percent	Totals
70	55	38.7	62	43.7	25	17.6	142
71	83	50.6	61	37.2	20	12.2	164
72	64	41.0	55	35.3	37	23.7	156
73	67	43.8	65	42.5	21	13.7	153
74	53	37.1	73	51.0	17	11.9	143
75	66	41.8	79	50.0	13	8.2	158
76	66	43.7	63	41.7	22	14.6	151
77	71	40.1	80	45.2	26	14.7	177
78	69	36.9	105	56.1	13	7.0	187
79	90	41.3	96	44.0	32	14.7	218
80	69	37.5	90	48.9	25	13.6	184
81	48	32.2	90	60.4	11	7.4	149
82	70	39.1	91	50.8	18	10.1	179
83	102	49.3	88	42.5	17	8.2	207
84	70	43.5	61	37.9	30	18.6	161
85	79	39.7	107	53.8	13	6.5	199
86	86	49.7	79	45.7	8	4.6	173
87	80	51.6	58	37.4	17	11.0	155
88	76	45.5	78	46.7	13	7.8	167
89	60	46.9	60	46.9	8	6.3	128
Summary:							
Total:	1424		1541		386		3351
Average:	71	42.5%	77	45.9%	19	11.6%	168

This table shows the total number of fatalities for each type of collision accident in the Totals column. The Percent column is the percentage of fatalities of total collision fatalities contributed by each collision accident type. The summary data provides the cumulative 20 year total for fatalities in each category, and the average percent and average no. of fatalities for each year.

Table 3-1

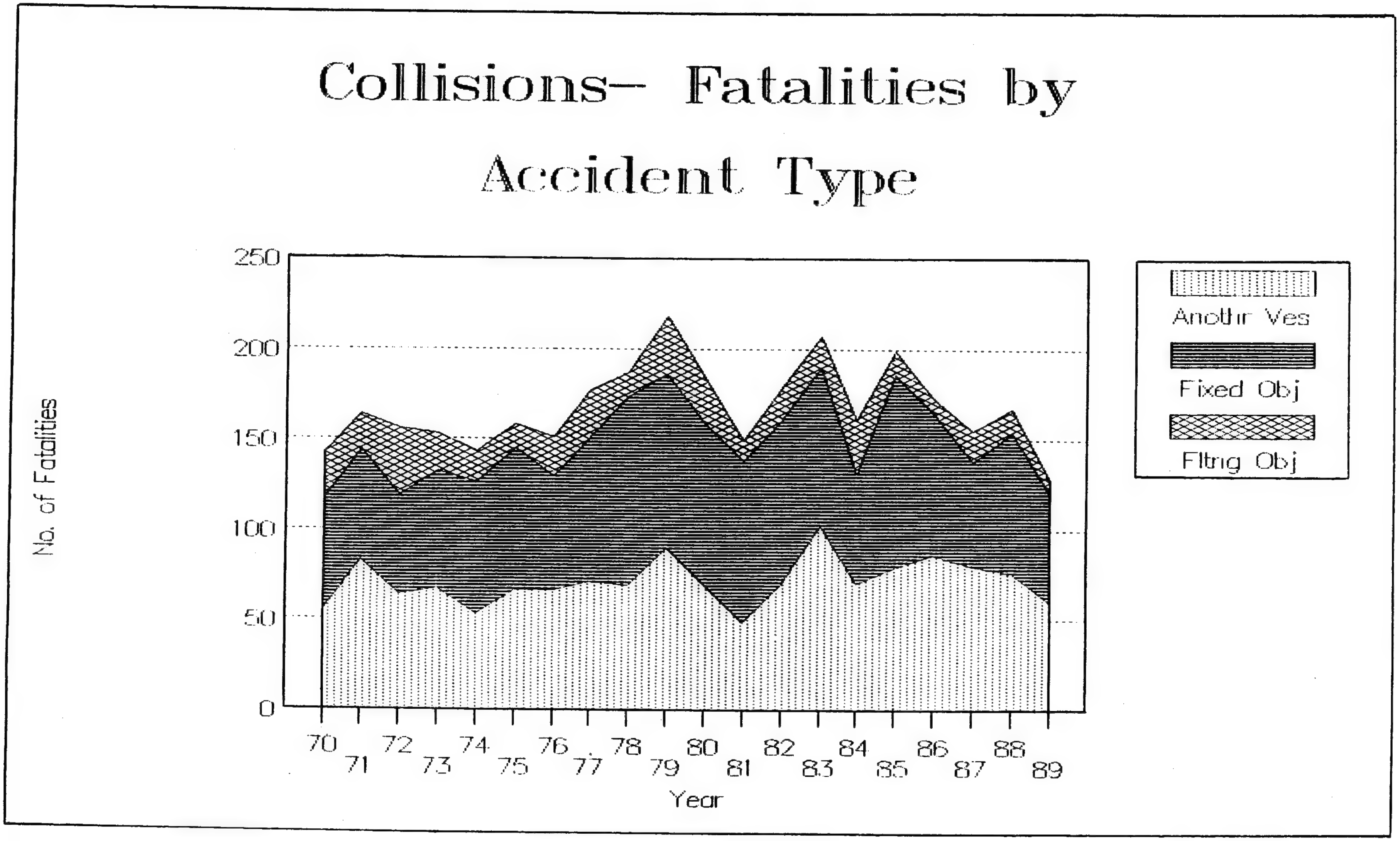

Collisions— Fatalities by Accident Type
No. of Fatalities
250
200
150
100
50
0
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Anothr Ves
Fixed Obj
Fltng Obj

Figure 3-1

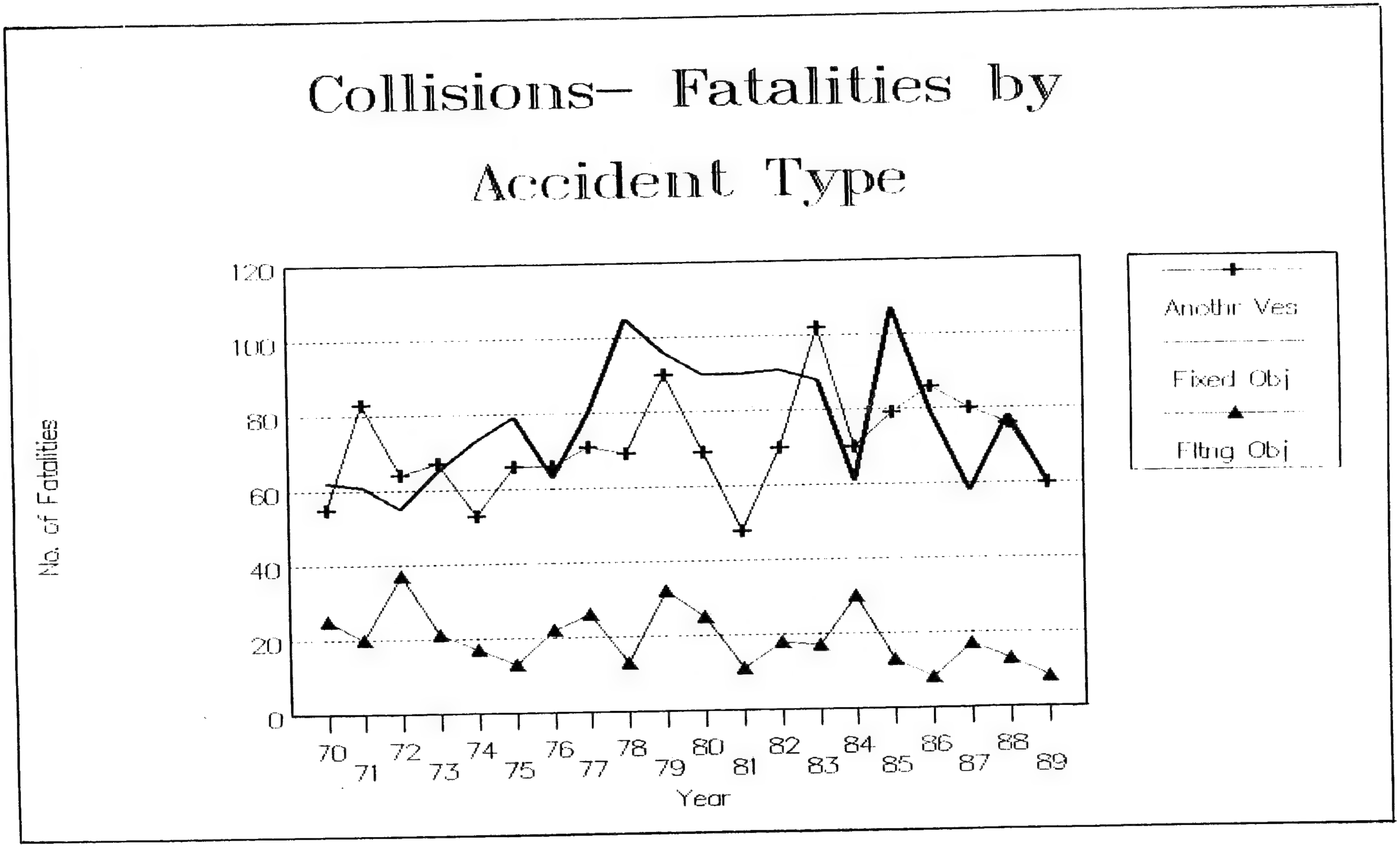

Collisions— Fatalities by
Accident Type
120
100
80
60
40
20
0
No. of Fatalities
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89
Year
Anothr Ves
Fixed Obj
Fltng Obj

Figure 3-2

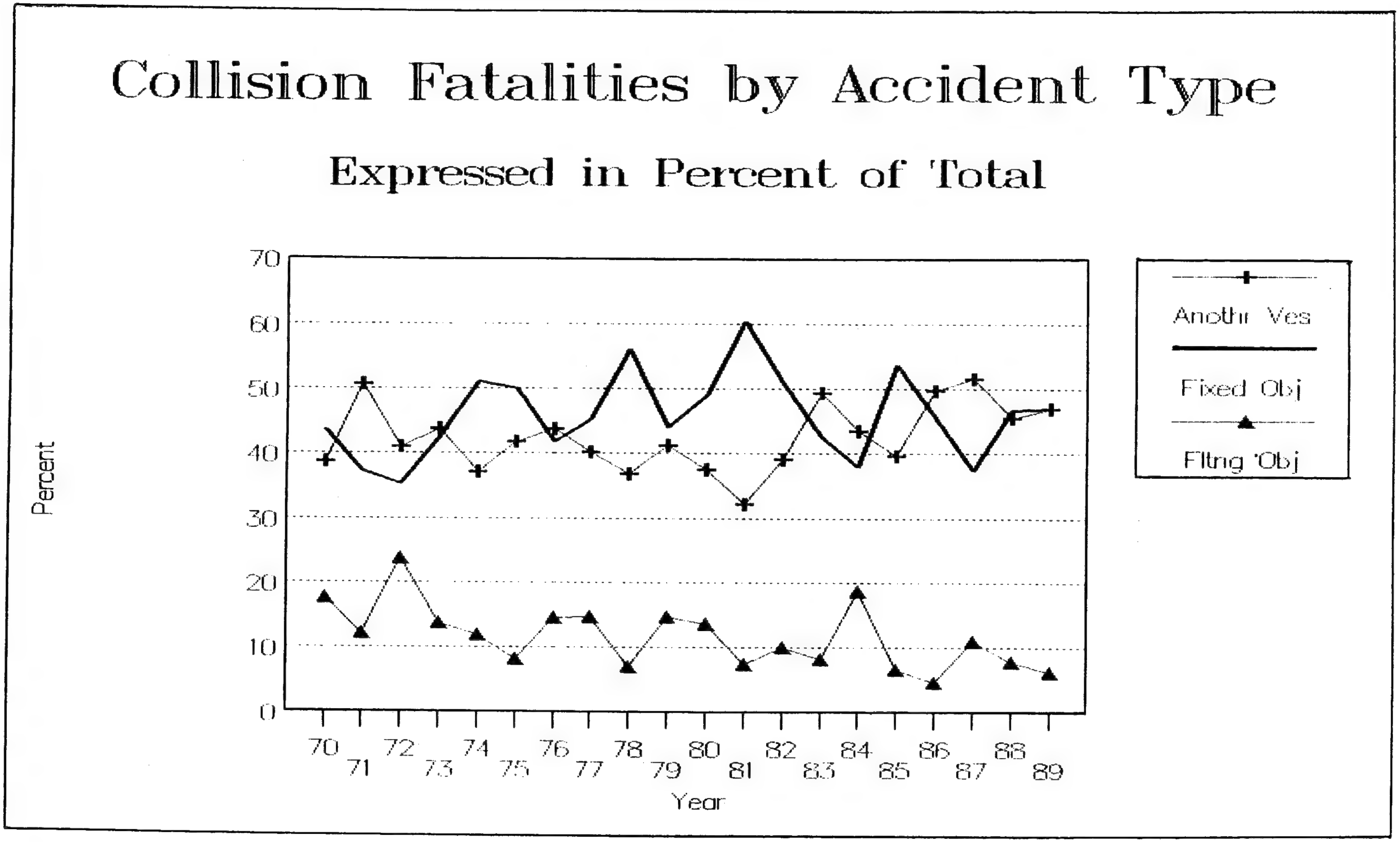
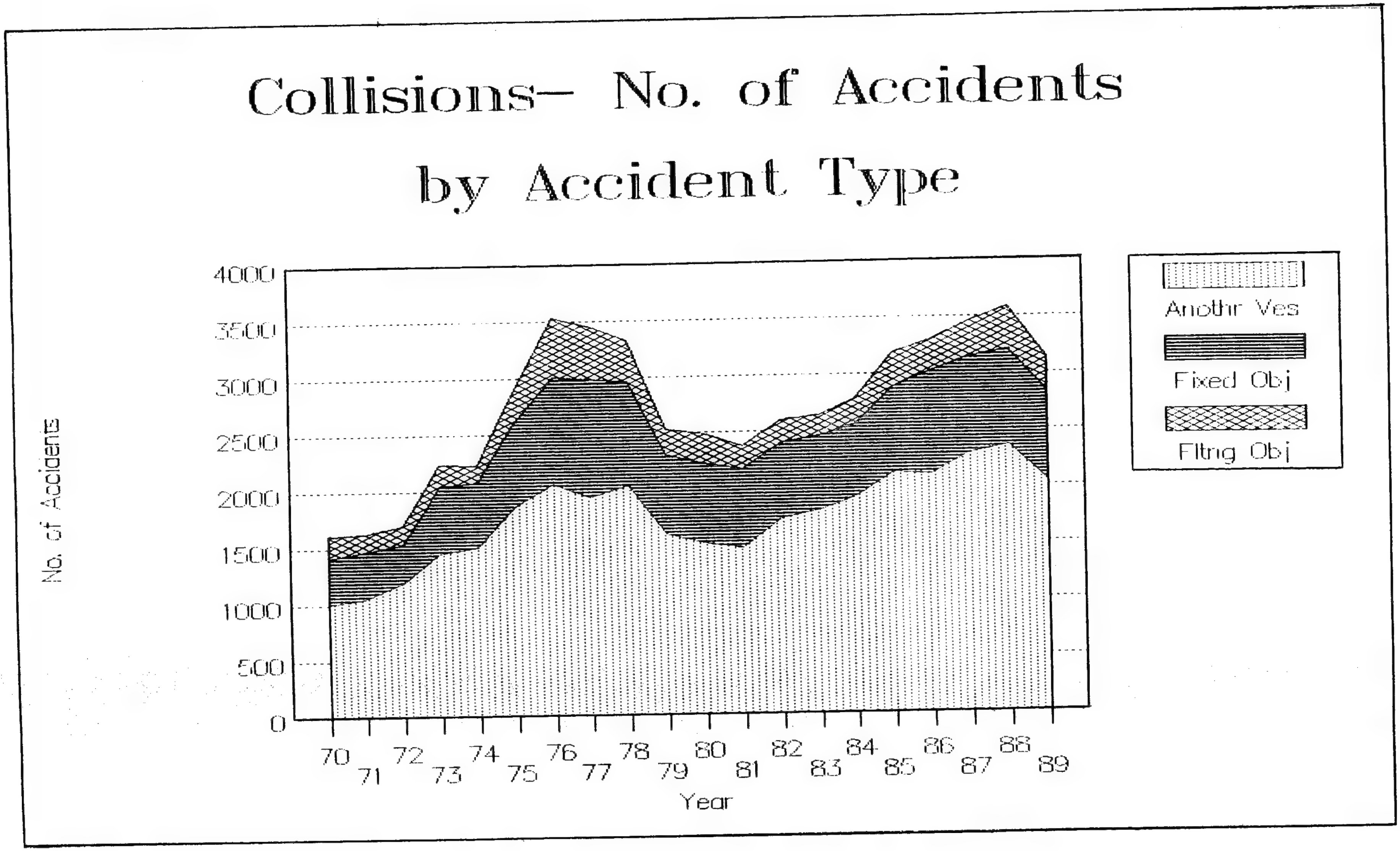
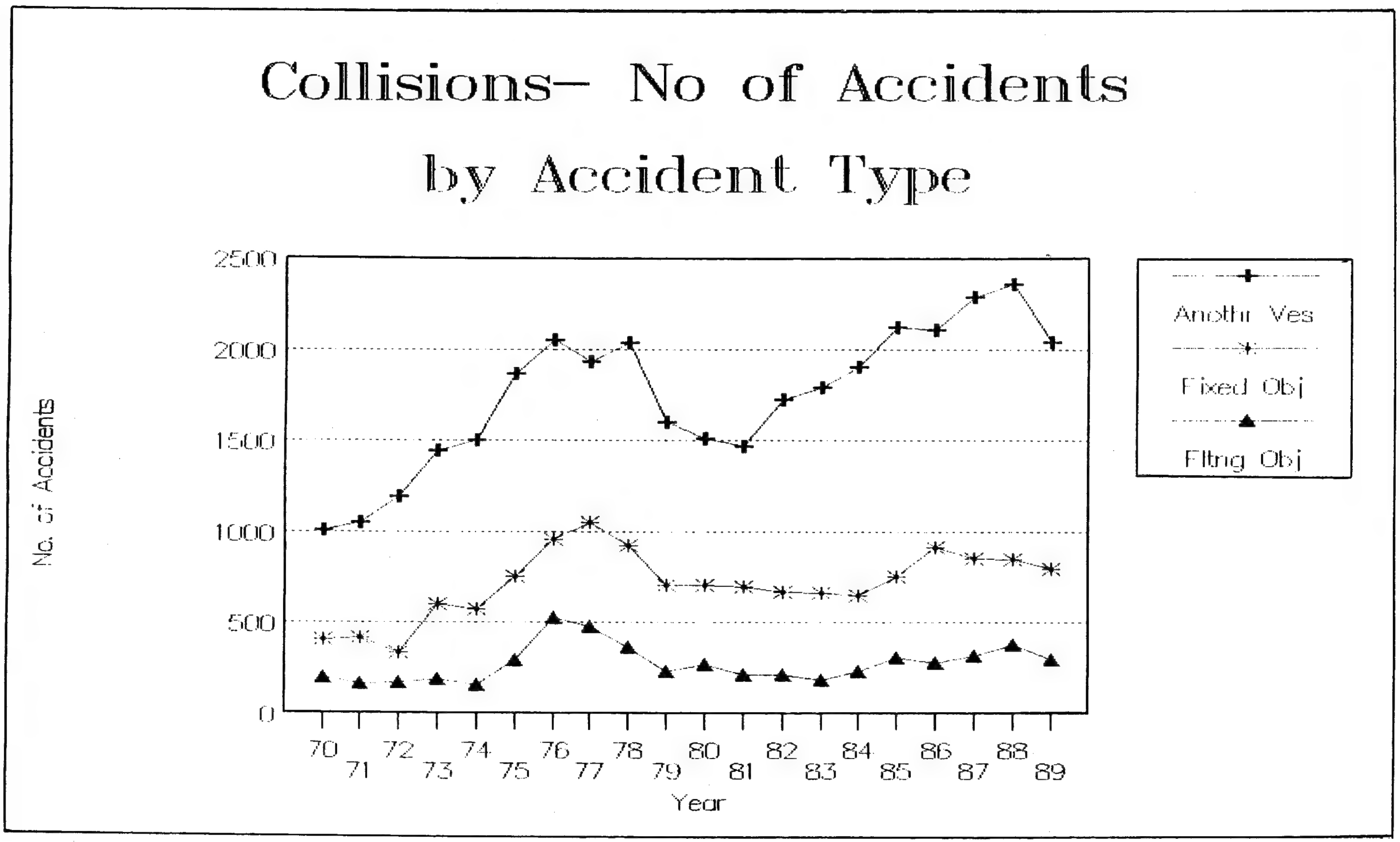

Collision Fatalities by Accident Type
Expressed in Percent of Total
Percent
70
60
50
40
30
20
10
0
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Anothr Ves
Fixed Obj
Fltng 'Obj

Figure 3-3



Collisions— No. of Accidents
by Accident Type
No. of Accidents
0
500
1000
1500
2000
2500
3000
3500
4000
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Anothr Ves
Fixed Obj
Fltng Obj

Figure 3-4



Collisions— No of Accidents
by Accident Type
No. of Accidents
2500
2000
1500
1000
500
0
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Anothr Ves
Fixed Obj
Fltng Obj

Figure 3-5

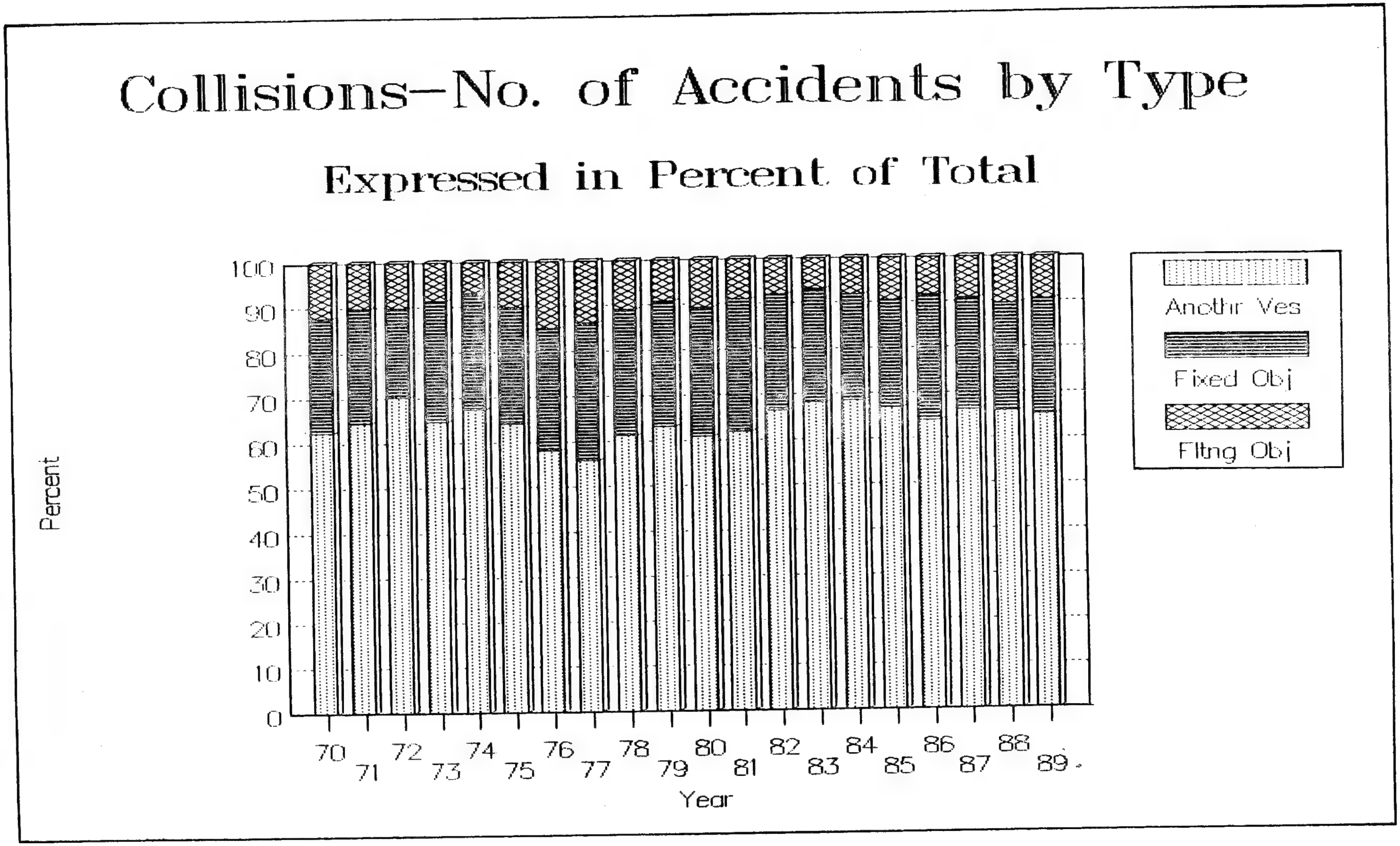
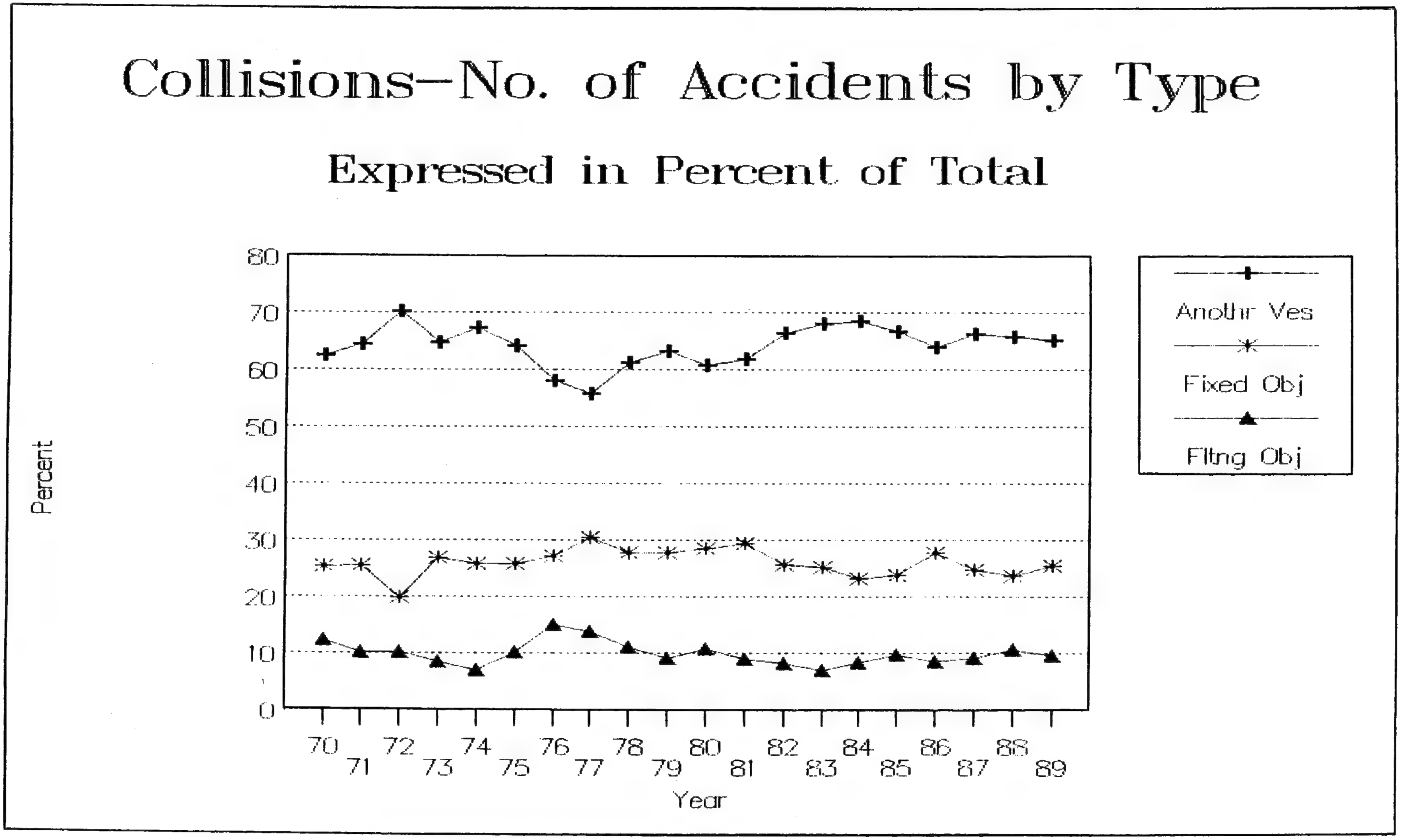

Collisions—No. of Accidents by Type
Expressed in Percent of Total
Percent
100
90
80
70
60
50
40
30
20
10
0
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Anothr Ves
Fixed Obj
Fltng Obj

Figure 3-6



Collisions—No. of Accidents by Type
Expressed in Percent of Total
Percent
0
10
20
30
40
50
60
70
80
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Anothr Ves
Fixed Obj
Fltng Obj

Figure 3-7

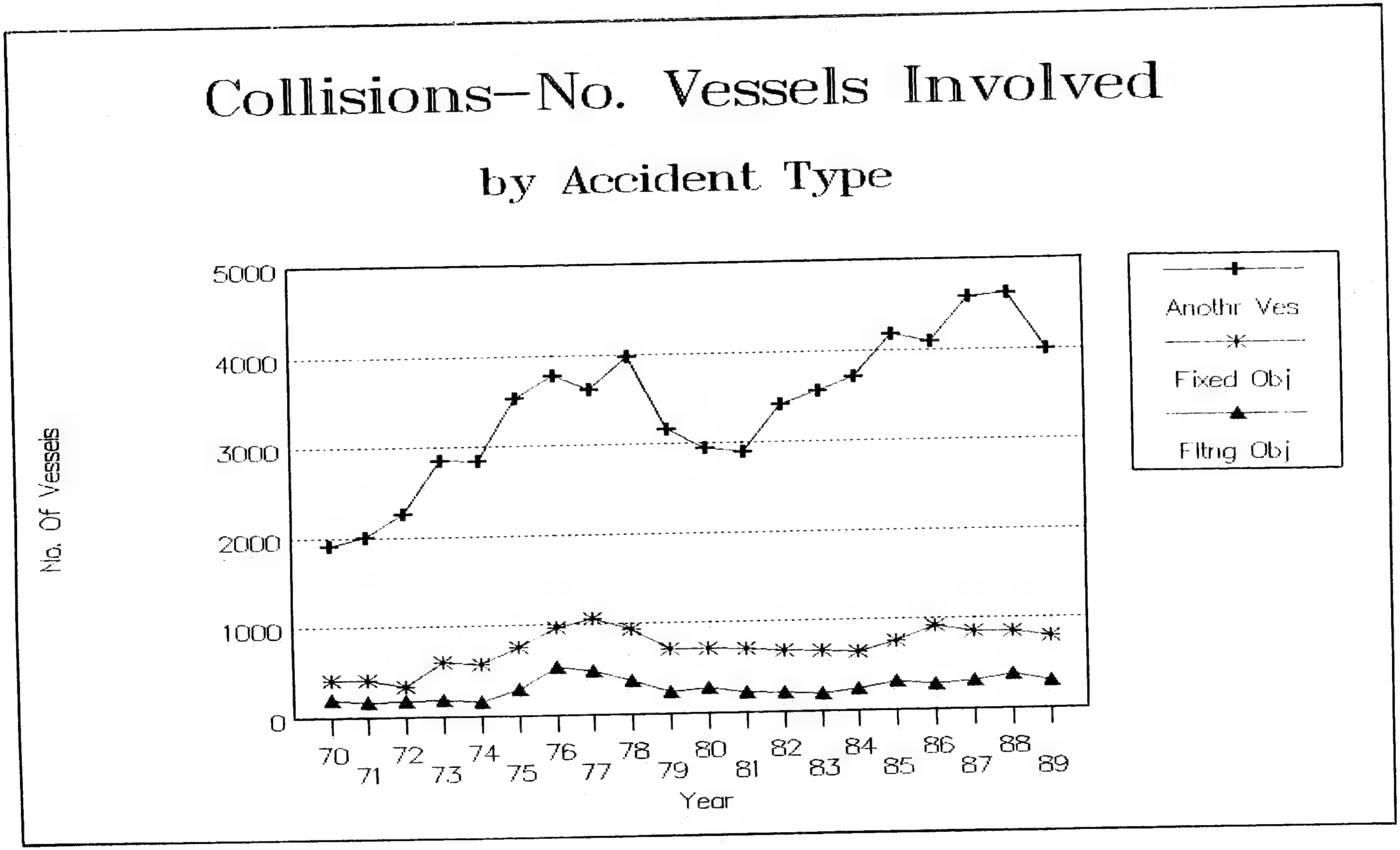

Collisions—No. Vessels Involved
by Accident Type
No. Of Vessels
5000
4000
3000
2000
1000
0
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
Anothr Ves
Fixed Obj
Fltng Obj

Figure 3-8

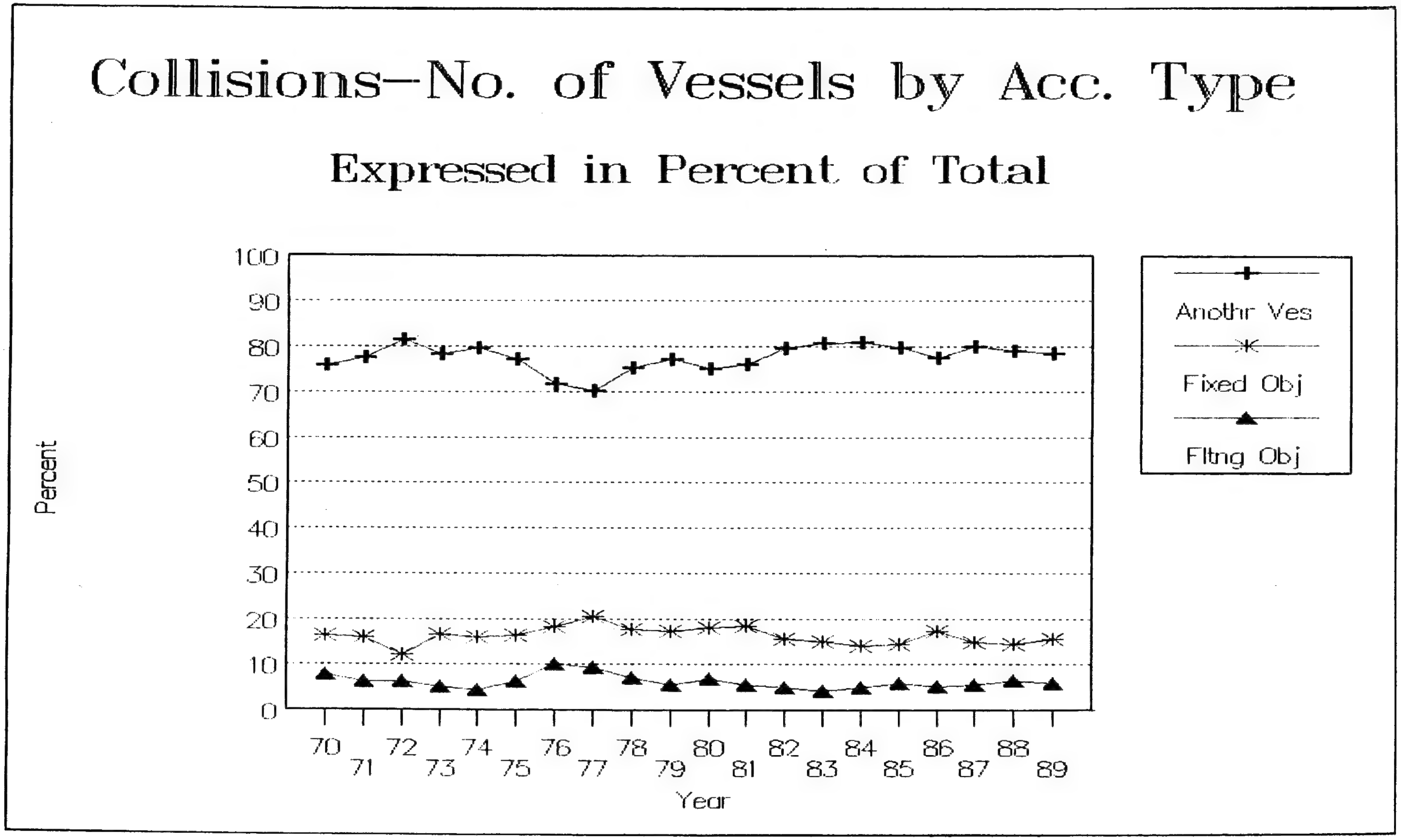

Collisions–No. of Vessels by Acc. Type
Expressed in Percent of Total
Percent
100
90
80
70
60
50
40
30
20
10
0
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89
Year
Anothr Ves
Fixed Obj
Fltng Obj

Figure 3-9

CHAPTER 4

DETAILED REVIEW OF ACCIDENT REPORTS

4.0 Introduction

Chapters 2 and 3 provided an overall analysis of accident data relating to collisions based on the USCG annual boating statistics. It is too easy to lose sight of the all important details of accidents if you just study the big picture. To gain a more detailed perspective of real collision accidents, we undertook two important efforts. First, we analyzed ten field accidents first hand, and secondly, we analyzed in detail more than 100 accident reports. The latter is the focus of this chapter. The field accident studies will be discussed in detail in a later chapter.

The analysis of real world data does not always consist of data that can be conveniently plotted, graphed, and tabulated. This type of data is often so sanitized that the human element has been lost. By carefully analyzing the details of many different accidents, it was hoped that certain trends and patterns would emerge that would never be obvious by just looking at numbers or graphs based on the USCG annual statistics. This effort was conducted to discover information that goes beyond recorded statistics.

While the USCG annual boating statistics include information on collision accidents, there are some missing pieces of information. The category of collisions known as Collisions With Another Vessel (CWAV) is unique in that it always involves at least two vessels, while the other accident categories typically only involve one. The data often missing from the USCG statistics are the details concerning the second vessel involved. Many states use accident report forms that permit detailed information to be recorded only about one vessel. Information about the second vessel involved may be limited to the operator's name, address, and the type of the vessel. To obtain detailed information about the second vessel, a second report form needs to be filled out. Filling out a second report form may require the investigator to repeat recorded data, and does not seem efficient to an already over-burdened investigator. Thus, the second form is often not completed, which means that an opportunity to learn valuable information about the accident is lost. Even when both forms are completed, they must be identified as being associated with the same accident, and filed together to relate them to the same accident. Many states do use a form which permits details to be recorded on both boats involved in a collision. Knowing the description of both boats involved helps considerably in obtaining a clearer picture of the collision scenario. The use and development of a form which contains information on both vessels would help to solve at least part of this problem.

From Chapters 2 and 3, we can clearly see that CWFXO (Collisions With Fixed Objects) result in about the same number of fatalities as CWAV (Collisions With Another Vessel). We were anxious to find out the details behind these numbers. What are these vessels hitting, and why are there so many fatalities in this category? Since the numbers of accidents in the CWFXO category is well below that of CWAV one would have hoped for a correspondingly lower number of fatalities. This is not the case, and we wanted to know why.

4.1 Scope

This portion of the research included a detailed analysis of all three collision accident types, CWAV, CWFXO, and CWFLO. In addition, we also looked at grounding accidents. Grounding accidents were considered because we knew from early preliminary research that some CWFXO accidents were incorrectly coded as groundings. The accidents analyzed included both fatal and non-fatal accidents, but the emphasis was more on the former.

4.2 Purpose

The researchers made some basic assumptions concerning the ultimate purpose for which the data gathered would be used. The data were gathered for these purposes:

1. To determine what can be done to minimize the number of collision accidents.

2. To determine what can be done to minimize the numbers of injuries and fatalities for those collision accidents which do occur.

The rest of the questions, goals, and information to be obtained center around these two purposes.

We analyzed each report in detail to learn about events in each accident that are not recorded or analyzed anywhere else in the statistics. This helps significantly in the quest to understand the problem.

The potential benefits and uses of the data collected from this project were carefully considered before entering this portion of the research. A series of questions was developed as they related to each type of accident. That is, some questions related to all accidents types while others related only to CWAV, CWFXO, CWFLO, or groundings. The specific questions developed are listed below.

For all accidents reviewed:

1. Are there any common scenarios or causes?

2. Are occupants commonly injured or killed? If so, how?

3. Are the occupants typically thrown out of the boat or do they remain with the boat during a collision? If they are thrown out, is drowning the cause of death? If the occupant drowned, was a PFD worn?
4. Are the occupants of small boats more likely to be injured than those in large boats?
5. Do operators generally take evasive action ?
6. What problems exist in the current accident recording process?
7. Does the vessel generally sink, swamp, or capsize after the accident?
8. Was the accident at night?
9. How fast were the boats traveling?
10. Was alcohol a factor?
11. What sizes of boats are commonly involved?

For CWAV (Collisions With Another Vessel):

12. Do the small boats generally run into larger boats or vice versa? In other words, is there any evidence to support the theory that it is more difficult to see from a large boat, or that smaller boats are more difficult to spot?
13. What type of impact occurred? Was the impact an over-ride, glancing blow, direct impact, partial impact or combination of these?

For CWFXO (Collisions With a Fixed Object) and CWFLO (Collisions With a Floating Object):

14. What was the object struck?
15. What type of an impact occurred?
16. Why is there such a high rate of fatalities in the CWFXO and CWFLO categories?

For Groundings:

17. Why did the vessel run aground?

In general, the researchers noted any problems with the data, such as lack of complete reports, and obviously erroneous information.

4.3 Method

Once the purpose and goals of the accident review portion of the project were established, a list of questions and forms were created to assist with the tabulation and analysis of the gathered data.

It was not feasible to tabulate, record, and analyze every piece of information on the detailed reports, therefore, only certain data were taken from each report. A wide variety of reports on collision accidents were reviewed.

The accident reports reviewed came from two sources. First, one state volunteered to participate and permitted us to review reports of all accidents in that state for one year that fit our criteria list. Second, the USCG provided a list of all accidents that fit our criteria, nationwide, and allowed us to review selected reports.

4.3.1 The State Accidents

The cooperating state was asked to provide a summary list of all accidents and access to reports that fit the criteria. The criteria used were all accidents involving a CWAV, CWFLO, CWFXO, and groundings for the calendar year 1989, and for a portion of 1990. Since this list included all accidents reported that fit our criteria, both fatal and non-fatal accidents were included. This provided an opportunity to understand what types of collisions occurred which may frequently result in serious injuries or property damage, but that did not necessarily result in a fatality.

4.3.2 The USCG Accident Reports

Since the USCG has thousands of reports that involve collisions, it was determined that the best approach was to look at those accidents that result in fatalities, and which statistically, were believed to be reasonably accurate. The criteria included all FATAL accidents in the four major categories of interest which were CWAV, CWFLO, CWFXO and groundings. All accidents occurred in the calendar year 1990. The USCG provided a summary list of all accidents which met this criteria, which can be found in Figure 4-1. The explanation of codes used in the summary list is found in Figure 4-2.

The accident list was still quite long; therefore, we reviewed it to determine the next best method of reducing it to a manageable size. This was decided by default because only certain states' reports were actually available for us to review.

The reports we received from the USCG were primarily reports completed by the investigating officer. Operator reports were also submitted and reviewed when available. If conflicting data was found on the operator's report when compared to the investigator's report, the investigator's report was used. Often witness statements were attached which provided valuable information not found on the accident report form.

4.4 Methods of Analysis

4.4.1 Overview

Forms were created on which to tabulate specific data items. The forms used for the USCG supplied reports are shown in Figure 4-3. Similar forms were used for the State reports. One set of forms was filled out for each accident. After the forms were completed, a computer database was set up with one field type representing each critical area on the form. Each accident was then summarized as one record. All data were entered into one common data table for analysis. This was done so that totals and summary data involving all accidents could easily be generated. The data was subsequently entered into a database program to assist with the analysis.

We also adopted certain conventions to provide consistency in recording and tabulating the data. For example, a consistent method to identify vessel number one and number two in a CWAV type accident was adopted. This method proved most useful and is explained below.

When two boats collide, usually one can be considered to be the impacting boat, and one the struck boat. Often they are referred to as the bullet boat and the target boat. Generally the bullet boat is easily identified because its bow impacted the other boat. In some cases, such as head on accidents, the bow of both boats may be considered to be equally involved in the impact and thus one cannot clearly be defined as a bullet boat or a target boat. In this case, the terms bullet boat and target boat are arbitrarily assigned. In the data summaries that follow, the impacting boat, or bullet boat, is always labeled as vessel number one. The struck boat, or target boat, is labeled vessel number two.

For accidents involving only one vessel, such as CWFLO or CWFXO the vessel data was recorded only as vessel number one. Vessel number two questions were left blank.

4.4.2 Explanation of Data Collected

In this section we will look briefly at the forms used to tabulate this data, and explain why some of those items were deemed critical for this analysis. Since many of the items on the form are not part of the standard report forms used by the states, it was often not possible to retrieve the desired information. The narrative reports were heavily used to attempt to locate key information such as estimated vessel speeds, number of persons thrown overboard, and directions of impact. We will only go into the rationale for those items that are not self-explanatory or for which additional explanation is necessary. The item numbers in the section that follows correspond to the questions on our data sheet found in Figure 4-3.

A. ID No. - All accident reports are assigned some type of case or ID number. This was recorded so that if any additional data was needed on a particular accident it could be readily identified.

1A. Hit and Run - It was not uncommon to find in a CWAV type accident, that the striking vessel left the scene following the accident. We decided that it would be a good item to track. We even noted that some states had a place on their accident report forms for this information.

2. Light - It was important to note if a collision occurred at night. Navigation lights play an important role in nighttime collisions, therefore we wanted to identify the ambient lighting conditions at the time of the accident.

3. Visibility - This is a subjective item and was taken from the accident report form when completed.

4. and 8. Length - The boat length is an item of critical importance. It was necessary to obtain the length of both boats involved to answer certain questions regarding the collision scenario. We were interested in attempting to identify any patterns with regard to boat size. For example, was it far more common for a large boat to run over a smaller one, or were the occupants of small boats more likely to be injured in an accident?

5. and 9. Type of Vessel - Most of the vessels involved in these types of accidents were open motorboats or vessels with a small cabin. Many of the cabin vessels have provision for steering either inside or outside the cabin. One early goal was to determine if operators who steered these type vessels from inside a cabin were more likely to be involved in an accident. If the type of vessel was checked as other, the actual vessel type was recorded. The data were later reviewed to identify any types of vessels which showed up frequently.

6. and 10. Operator Steering Position - This applied only to cabin boats with more than one steering position as explained in the preceding paragraph.

7. and 11. Manufacturer or Model of Boat - This information was recorded mainly for the sake of completeness. Sufficient data were not available nor was there any attempt to correlate injuries or fatalities to a certain manufacturer's boat.

7.1 and 11.1 Horsepower and 7.2 and 11.2 Horsepower and Engine Type - This data was primarily used to help identify the type and size of craft involved if other information was absent. For example, many reports would leave off the boat length, but if the field report said that it was equipped with a 5 HP outboard motor, we had a better idea of what kind of boat was involved.

12. and 17. <u>No. of Occupants</u> - This is simply the number of persons on board. Generally, this information was recorded on the accident report, but often for only one vessel.

13. and 18. <u>No. Injured</u> - The initial goal was to track the number of persons injured on each craft. Injury data was often not filled in on the reports at all, especially those prepared by an investigator. Most of the injury data tabulated in our summary was derived from narratives and witness statements. Operator reports were generally more detailed than the investigators' reports with regard to providing details on injuries.

14. and 19. <u>No. Fatalities</u> - This is the number of people killed on the boat.

15. and 20. <u>Location of Occupants Injured or Killed</u> - The initial goal was to try to identify locations of occupants in a boat. This is especially important in CWAV type accidents. An occupant's location may determine the likelihood of being ejected from the boat or injured during a collision. Few of the reports reviewed had any information regarding occupant locations. At least one state includes provision for a seating diagram on their standard report form. The data on this item was generally not available, so no tabulation of this data was made.

15A. and 20A. <u>No. of Occupants Thrown Overboard</u> - This data is critical for many reasons. It is important to understand why people are killed or injured in a boating accident. One goal in this area was to help separate fatalities due to injuries from those due to drownings. It was also useful in identifying the types of accidents in which occupants are thrown overboard. This data was not on the report form, but could often be obtained from narratives.

15B. and 20B. <u>No of Deaths by Drowning from Occupants Thrown Overboard</u> - Many states' reports contain spaces for information on cause of death. Some also include spaces to note if the victim was wearing a PFD. Unfortunately, this data was often not completed by the investigator, leaving an important void in this area. The data is important so that the circumstances for the fatalities can be documented if known.

16. and 21. <u>Cause of Injuries/Death For Occupants Not Thrown Overboard</u> - This information was only available on very few of the reports reviewed. The reports almost never contained information on what happened to surviving occupants. Injuries were often not recorded, and when notations were made, few details were provided.

22. CWAV Basic Situation - This data answers the fundamental question "Was the target boat sitting still when struck by the bullet boat?" Obtaining information on the basics of the situation helps to categorize the general circumstances in which accidents take place. The answer of "Vessel No. 2 moving very slowly relative to impacting vessel" was necessary for those situations where the struck vessel was only idling or traveling very slowly.

23. and 24. Estimated Speeds of Vessels - Estimated speeds were recorded only in relative terms. This information was difficult to extract from the reports since most states' forms do not have a space for this information. We did find one state which had a block entitled "Operator's estimate of his boat's speed." This information is useful, but is perhaps best expressed only in relative terms such as on plane, well below planing speed, and so forth. Many boats do not have speedometers. Therefore an operator's estimate of his boat's speed on the water may be inaccurate. Often a speed was estimated by our researcher based on narratives or other descriptive data. When in doubt, the speed estimate was conservative, making our estimate most likely lower than the actual speed.

25. Type of Impact - Impacts in CWAV type accidents are usually in the form of over-rides, glancing blows, penetrating impacts, or some combination thereof. Narrative descriptions or descriptions of damage to the boats usually permitted an assessment of the type of impact. Knowing how boats commonly collide can help to provide data to identify problem areas.

26. Initial Contact Area of Impacted Vessel: Where was the target vessel struck? Insufficient data was available on most reports to make this determination. At least one state's forms had a diagram with provision to show all damaged areas. This can help but in an accident with extensive damage, the initial contact area may not be obvious.

27. Initial Contact Area of Impacting Vessel: The answer to this one may sound obvious as most people automatically assume that the bow is the first part of the striking boat to make contact with the target boat. Last second evasive action can result in one boat literally skidding into another boat. In the beginning, we wanted to identify any accidents where this took place, however there was not sufficient data to prove anything other than bow contact first on almost all accidents reviewed.

28. Direction of Impact from Vessel Two's Perspective - If you are the operator of the struck vessel, this answers the question "Which way did that guy come from?"

29. Relative Size of Vessels - This field identifies if both boats were about the same size, if one was larger than the other, or if both were about the same size but different types. This field was established to help look for trends in collisions as related to boat size. For example, are boats that are involved in collisions usually about the same size, or is one usually significantly different from the other? It was also realized that two boats could be the same size (length), but be of very different types. For example, a 16 ft canoe is very different from a 16 ft ski boat.

30. Size and Geometry of Vessels - Did the large boat run over the smaller one or vice versa? In some accidents, such as head on collisions, both boats may be considered to be "equally involved" in the impact. It was used to help answer the question, "Does the large boat usually collide with the smaller one, or is the reverse true?"

The following parameters applied only to CWFXO and CWFLO accidents. Again, only parameters that require explanation are noted below.

32. Type of Impact - It was important to attempt to note how the boat struck the object. Many collisions with fixed objects are glancing blows rather than a direct impact, such as a collision straight on with a seawall. This data was important to assist with analyzing accidents with respect to potential for causing injury.

39. Boat Response - To help analyze the seriousness of the accident, it was noted whether the boat swamped, sunk, or capsized following the collision.

41. Comments: The most important parts of this section noted if alcohol was involved, and if evasive action was taken by either operator.

42. Opinion of Officer as to Cause: Unfortunately, this section was often left blank by the investigating officer, but the information was noted when available.

4.4.3 Looking for Common Trends

In an effort to identify common trends or patterns, attempts were made to identify data for each accident, much of which is not located on the standard report forms. Most of the data regarding common trends was located in the narrative sections of the reports or in witness statements.

4.5 Summary of Results

4.5.1 The State's Accident Data

The accident reports provided by our volunteer state which met the criteria in 4.2.1 totaled 152 accidents. Remember that this data included both fatal and non-fatal accidents. More than fifty of these accidents were reviewed in detail. Thirty-three accident reports provided sufficient detail to make a judgement as to whether the accidents would be considered severe. A severe accident was considered to be one in which large amounts of property damage to one or both boats occurred, or where injuries requiring treatment beyond first aid were noted. Twenty-one of the 33 non-fatal accidents (63%) were considered severe. Several of the accidents that were not considered severe were near misses that could have easily been severe except for last second evasive action on the part of an operator. Although the sample is far too narrow to be statistically significant, the indication is that most of the accidents reported are relatively severe in nature. Data tabulated with regard to injuries and property damages, on non-fatal collisions, was often not of sufficient detail to make an accurate assessment of the severity of the accident.

Common non-severe accidents included docking accidents, very low speed collisions, glancing blows at higher speeds, and collisions where the occupants were ejected from the boat but were not injured. Cuts and bruises were the most common injury reported in non-severe accidents. Some of the more severe injuries included broken limbs, cracked ribs, collapsed lungs, and injuries to the neck and collarbone.

Several accident reports support a theory that an occupant sitting in the seat, facing forward during a CWAV accident is at some risk of injury to the torso around the rib cage. It appears that the injuries may be due to the occupant's impact with the interior of the boat. At least two hypotheses exist to account for injuries due to the occupant's impact with the interior of the boat.

One possibility is that during a T-bone CWAV accident, the lateral acceleration experienced by the struck boat is sufficient to create an impact between the occupant and the interior of the hull side. One person involved in such an accident stated that her ribs hit the side of the boat. This phenomenon could be similar, although less severe, than certain side injuries experienced during side impact accidents in automobiles. Testing and additional research would be necessary to evaluate the accuracy of this hypothesis.

A second possible explanation of how occupants may be injured by impacting the interior hull side occurs during over-ride accidents when the bullet boat becomes airborne. Observations of experimental collisions involving over-rides have lead to the conclusion that many times the bullet boat may re-enter the water

at a significant heel or roll angle. The jolt experienced by the occupants at water re-entry while the boat is rolled significantly to one side may also place the occupants at risk of injury due to impacts with the hull side interior. Additional data and testing would be necessary to evaluate this hypothesis.

Of the fifty accidents reviewed, seven involved one or more fatalities. These seven accidents were added to the fatal accident analysis conducted on the data provided by the USCG discussed in the next section.

4.5.2 USCG Accident Data

The USCG provided a summary list of all accidents meeting the criteria listed in paragraph 4.2.2 above. In total, 159 accidents met this criteria. The summary list and the accident codes are provided in figure 4-1 and 4-2 at the end of this section. The breakdown by accident type is as follows:

Accident Type	Number of Accidents
CWAV	70
CWFXO	66
CWFLO	12
Groundings	11
Total	159

Complete accident reports for 55 of the 159 fatal accidents covering 19 states were obtained from the USCG. Four of these accidents were groundings. None of the data from the grounding accidents was included to the computer database for analysis. These accidents were correctly coded as groundings and were not collisions. An additional four accidents were incorrectly coded, or considered too incomplete to provide data for the analysis.

This left 47 accidents provided by the USCG that were placed into a database for analysis. To this data, the seven fatalities from our volunteer state were added thus bringing the total accidents included in the computer analysis to 54. The detailed reports obtained from the USCG did not already include data from our volunteer state, ensuring that there was only one report for each accident. The majority of the results in the sections that follow are based on the analysis of these 54 accidents. The breakdown by accident type is listed below:

Accident Type	Number of Fatal Accidents
CWAV	25
CWFXO	21
CWFLO	8
Groundings	0
Total	54

4.6 Analysis of CWAV (Collision With Another Vessel) Accidents

As a reminder, vessel number one is always referred to as the bullet boat, and vessel number two is always referred to as the target boat. For accidents where neither vessel was clearly identified as a target boat or bullet boat, the designations of Vessel 1 and Vessel 2 were arbitrarily applied. Head-on collisions are a good example where the latter statement applies.

The following analysis applies to the 25 fatal CWAV accidents which were contained in the 54 fatal accidents closely analyzed, as summarized in the table above.

4.6.1 Effect of Vessel Size and Role in a Collision

4.6.1.1 Bullet Boat Vs. Target Boat

Two factors emerged as having a definite effect on the potential for fatalities in an accident. Whether or not the boat was the bullet boat or target boat, and the relative size of the vessel were two factors that had a direct effect on what happened to the occupants.

The one pattern that stood out the most was the relationship between the boat's role in the collision and the risk of injury or death to its occupants. The boat identified as the target boat (which was always labeled as Vessel No. 2) suffered the most in a collision. In 15 of the 25 fatal collisions examined, more fatalities occurred in the target boat than in the bullet boat. The same number of fatalities occurred on each boat for three of the collisions. This data suggest that the occupants on board the target boat are generally at greater risk of death.

In seven of the 25 collisions, more people were killed in the bullet boat than in the target boat. What happened in these seven collisions that could account for the difference in the above trend? In at least six of these 7 collisions, the bullet boat was smaller than the target boat. (For one accident, the length of the second boat was not known.) In one case, a small runabout impacted a large, steel hulled houseboat, killing one occupant in the runabout, and injuring three others. No one on the houseboat was injured. This is one example of where those in the bullet boat are at greater risk of injury than those in the target boat. The number of occupants on board each boat was taken into consideration for this analysis.

4.6.1.2 The Effect of Relative Size

In order to determine the effect of relative size alone, the number of accidents in which one vessel was known to be larger than the other were examined. The rule of thumb was that if the smaller vessel's length was 80% or less of the larger vessel's length, the

vessels were considered to be of different sizes. Since the lengths of both vessels involved were not always available, it was not always possible to determine if the boats were of a different length. However, in 17 of the 25 accidents, it was confirmed that the boats were of different lengths.

At first, we were looking to see if a trend existed that would support large boats more frequently striking small boats, or vice versa. For these limited number of accidents, there were about an equal number of each. The next question was to determine if there was a relationship between the size of the boat and the risk of death. To accomplish this, we wanted to isolate the number of accidents where the number of fatalities was greater on the smaller boat than on the larger boat. This applied only to the 17 CWAV accidents where the boats were determined to be of a different length.

In 13 of the 17 accidents, there were a greater number of fatalities on the smaller boat than the larger boat. These accidents can be further be broken down into two more categories. The two categories are those accidents where the smaller boat was the target boat and those where the smaller boat was the bullet boat.

There were seven accidents where the smaller boat was the bullet boat. There were more fatalities on the target boat in only four out of these seven accidents. There were 10 accidents where the smaller boat was the target boat. In at least nine of these 10 accidents, more people were killed on the smaller target boat than on the larger bullet boat. The number of occupants on board each boat at the time of the collision was then considered for each accident. After a review of the data, the general conclusion was reached that persons on board the smaller boat are more likely to be injured or killed than those on the bullet boat, especially when the target boat is also the smaller of the two boats.

The same type of analysis was performed with the number of persons thrown overboard and number injured. This analysis was performed looking first at the total number of persons thrown overboard on the bullet boat, and the target boat as a group. The same procedure was followed for number of persons injured on the bullet boat and the target boat. Figure 4-4 shows a summary of the results. The totals show that as a group, more persons were thrown out of the target boat (18 vs. 11), and were injured in the target boat (23 vs. 14), than in the bullet boat. This is significant since the number of persons on board as a group was about the same for the bullet boat and target boat (72 and 68 respectively). This data alone would suggest that there is an increased likelihood of injury in addition to being thrown overboard if you are in the target boat during a collision. It is also consistent with the analysis performed on fatalities. Caution in interpreting the data regarding injuries and persons thrown overboard is necessary in this case. While every attempt was made to pick out any data that

reflected injuries and number of persons thrown overboard, most reports simply lacked sufficient detail to obtain complete information. Thus the true accuracy of the conclusions regarding injuries and persons thrown overboard is unknown.

This data leads to three important conclusions:

Conclusion 1. During a collision with another vessel, the occupants in the struck boat are at much greater risk of being thrown overboard, injured or killed than the occupants of the striking boat.

Conclusion 2. For CWAV type accidents where one vessel is significantly larger than the other, the occupants of the smaller vessel are at much greater risk of death, injury, and being thrown overboard than the occupants of the larger boat. This is generally true even if the smaller boat is the bullet boat.

Conclusion 3. For CWAV, where the target boat is significantly smaller than the bullet boat, the risk of injury, death, and being thrown overboard is especially high, even more so than for conclusion #1) or conclusion #2) above for the occupants of the smaller (target) boat.

4.6.2 Common Scenarios

4.6.2.1 Near Head-On Collisions

Throughout the analysis, we were looking for common patterns or scenarios. One common scenario was the frequency of head-on or near head-on collisions. Six accidents out of 25 or approximately 24% of those fatalities reviewed were of this type. In several cases, it was recorded that both boats swerved in the same direction attempting to avoid the collision. One accident involved both boats swerving the same direction five different times before finally colliding! In only one accident did the waterway contribute to the accident. In that accident, two boats met each other at high speed while rounding a sharp bend in a river.

The exact cause of these accidents is difficult to evaluate. It is not known if the operators of vessels in these circumstances were aware of the proper procedures when faced with an approaching vessel. Clearly, both operators must be familiar with the rules of the road if disaster is to be avoided. Often alcohol, night background lighting, and operator inexperience all contribute to such events making it impossible to single out one factor as the cause of the accident.

4.6.2.2 Drownings Without PFDs

When the subject of collisions is discussed, it is important to know what is causing injuries and fatalities. While compiling the data from the accident reports, every effort was made to document any instances of a person who drowned either with or without wearing a PFD, as this was noted as a recurring event. Unfortunately, many accident reports did not include the cause of death, or if it was indicated as a drowning, they did not specify if the person was wearing a PFD.

The 25 CWAV accidents involved a total of 29 fatalities. Of these, at least 13 were known to be drownings. And of these 13 at least eight of these were not wearing a PFD. One case was noted where the cause of death was drowning and the person was wearing a PFD. However, no PFD data was provided for the other four known drowning cases where PFDs were being worn by the victims. In summary, in at least eight out of 29 fatalities,
(28%) in the CWAV accidents reviewed, persons drowned and were not wearing their PFDs.

It would presumptuous to state that all of these fatalities would have prevented if PFDs had been worn. No data was provided on other injuries, or the condition of those persons when they entered the water, thus making it impossible to determine if wearing a PFD would have saved their lives. However, it is likely that their chances of survival would have been improved dramatically if they had worn a PFD. One can initially conclude that more lives might be saved, even during collision type accidents, if the occupants would properly wear their PFDs.

4.6.3 Miscellaneous Parameters

In this section we will summarize data collected on some of the important parameters regarding the CWAV type accidents. The numbers in parentheses are the numbers from the questions on the report form discussed earlier in Figure 4-3 of this chapter.

Hit and Run (1A)

This item was placed on the form as we became aware that the operator of the striking vessel does not always stop to render assistance. Frequently, the operator of the striking vessel may not suffer any significant injury, and his vessel may be relatively undamaged, thus he is able to continue on his way after a collision. This occurred in at least one documented case in a CWAV fatality we reviewed. There were others of which we were aware that did not involve a fatality. At least one state has a block on their accident form to note if it was a hit and run situation.

Light (2) -

Number of accidents during daylight: 15
Number of accidents at night: 9
Number of accidents at dusk/dawn: 1

Vessel 1 Length (4) and
Vessel 2 length (8) -

Number of vessels of length (feet):

	Under 15'	15'-17'	18'-20'	20'-23'	24'+	Unknown
V1:	0	5	8	7	4	1
V2:	2	5	3	2	6	7

Type of Vessel: Vessel 1 (5) and Vessel 2 (8)

	om	cb	pw	sb	ot	tb	un
V1:	16	5	0	0	1	2	1
V2:	11	3	3	1	2	0	5

where
om = open motorboat
cb = cabin boat
pw = personal watercraft
sb = sailboat
ot = other
tb = tugboat
un = unknown

Collision Basic Situation (22)

The purpose of this item was to help evaluate the most frequent circumstances in which collisions occur. It is important to understand if most accidents occur when both vessels are moving, or perhaps when only one is moving and one is stationary. The latter category was subdivided into categories where the struck vessel was moving very slowly relative to the first vessel, or where its speed was essentially zero. The intent of the last two categories was to help distinguish between vessels that were operating at a slow cruising speed, and those which were probably not being operated at all. The concept was that if a vessel is struck while at zero speed, it was likely anchored, drifting, engaged in fishing, or other activity where its operator was engaged in something other than operating the vessel. The number of accidents for each is:

B: 15
1: 5
1s: 3
Un: 2

where
B = both vessels moving
1 = Vessel 1 moving, Vessel 2 stationary
1s = Vessel 1 moving, Vessel 2 moving very slowly
Un = unknown due to lack of data

Thus for the data reviewed, 15 out of 25 (60%) of the CWAV accidents occurred where both vessels were moving. In five of the 25 accidents (20%), the struck vessel was stationary.

Estimated Speeds of Vessel 1 (24) and Vessel 2 (23)

Estimated speeds of the boats involved are difficult to obtain. When reviewing the reports, if the operator provided an estimate of speed, and no data was found to the contrary, it was recorded as the estimate. If no estimate was provided by the operator, then attempts were made to obtain the data from witness statements or based on the scenario and damage data. Exact estimates were not required. A range of speeds was established to determine whether the boat was on plane, below planing speed, or in transition. If it was stated by the operator that the boat was traveling at 40 mph or more, this was recorded as very high speed. However, for CWAV accidents, no data was available on any of the accidents sufficient to show that either boat was traveling at 40 mph or more.

Estimated Speeds:

	h	m	l	0	u
Vessel 1:	15	1	4	NA	5
Vessel 2:	9	1	3	5	7

where:
h = high speed, on plane or 20 plus mph
m = medium speed, just below planing speed, or near hump speed but estimated below 20 mph (but more than 10 mph)
l = low speed, below hump speed, probably less than 10 mph
0 = zero speed, at anchor or drifting

The data shows that at least 15 out of the 25 (60%) of the bullet boats were on plane when the collision occurred. The data also shows that at least nine of the 25 (36%) target boats were on plane when the impact occurred. Unfortunately, speed estimates on the target boat were not available in sufficient numbers of accident reports to make any broad based conclusions.

It is interesting to note that in four of the accidents, the estimated speed of V1 was less than ten mph. Two of these accidents involved a tugboat which struck a second stationary or very slow moving vessel.

Type of Impact (25)

The type of impacts were generalized into the three main categories. The goal was to see what types of impact are most common, and if there is a correlation to type of impact and potential to injury or death. The impact types are intended to describe the primary impact mode, realizing that these are somewhat subjective judgements. Most over-rides for example, will involve at least some penetration of the hull perimeter.

Type of Impact:

Over-ride:	8
Glancing Blow:	4
Penetration:	1
Unknown:	12

It was not possible to determine the impact types for 12 of the accidents, due to a lack of information. For the thirteen accidents where it was possible, the most common type of impact was the over-ride. A review of previously conducted experimental collisions and a subjective evaluation of many officers' experience suggests that the over-ride type impact is by far the most common type of impact mode. It was established for eight of the 13 (65%) accidents where the impact type was known that an over-ride type impact occurred. It is probably reasonable to estimate that at least half of all fatal CWAV accidents involve an over-ride as the primary impact mode.

Evasive Action (38)

Attempts to evaluate the number of accidents where an operator was able to or attempted to take evasive action proved difficult. Again, lack of narratives or other details made this assessment almost impossible in most cases. This would be worthwhile information to obtain in future studies. However the accident reports we reviewed were not detailed enough on 18 out of 25 accidents to perform any meaningful analysis.

4.7 Analysis of Collisions With Fixed Objects (CWFXO)

In chapter 2 we saw that CWFXO type accidents for some years resulted in as many fatalities if not slightly more than CWAV, according to the USCG Annual Boating Statistics. In this section, we hope to learn a little more about why this is true.

A total of 21 CWFXO accidents were analyzed which accounted for 23 fatalities. Several patterns and common denominators emerged as the data were reviewed. Patterns and observations in several topic areas were observed, which include:

1. High number of persons thrown overboard
2. Canoeing/ river accidents
3. Jonboats
4. Common objects struck
5. Number of outboard powered boats involved

We will attempt to discuss in detail each of the significant common factors discovered.

4.7.1.1 Persons Thrown Overboard

Figure 4-5 contains a summary of the data regarding number of fatalities, injuries, persons thrown overboard, and persons on board. It becomes immediately obvious when this table is compared to Figure 4-4, which summarized the same data for CWAV, that persons on a boat in a CWFXO accident are more than twice as likely to be thrown overboard. Of a total of 66 persons involved in 21 CWFXO accidents, 40 were known to have been thrown overboard. For the fatal accidents reviewed, 61% of those involved were thrown overboard! For CWAV, even for the target boat, only 26% of the occupants on average were thrown overboard during a collision.

It was documented that for at least 11 of the 21 CWFXO accidents, all the occupants on board were thrown out of the boat upon impact. This is a much higher number than could be established for CWAV type accidents.

Of the 23 fatalities involved, at least 12 were known to be due to drowning. At least five of these 12 victims were not wearing a PFD. Unfortunately, most reports did not indicate if the persons that were thrown overboard and drowned were wearing a PFD.

4.7.1.2 Canoeing and River Accidents

A recurring accident scenario involved human powered craft on rivers. Five fatal accidents of the 21 reviewed (24%) involved canoes, kayaks, or rafts. The specific craft were 3 canoes, 1 raft, and 1 kayak. During a typical scenario, the craft struck a rock, or other obstruction, overturned, and the occupants drowned. In at least two of these accidents, the victim was not wearing a PFD.

4.7.1.3 Jonboats

While searching for patterns and common denominators, it was repeatedly observed that jonboats were involved in CWFXO accidents.

What is a jonboat anyway? A jonboat is typically a lightweight open boat, 12 to 14 feet in length, constructed of aluminum or occasionally plastic. They are typically powered by a small outboard motor, usually 20 HP or less.

Our researchers noted that jonboats were involved in at least five of the 21 (24%) CWFXO accidents. A typical scenario was described as the craft striking an object, which was "probably a submerged stump." The occupants were then thrown overboard.

This was not easy information to obtain since accident report forms do not distinguish between an open motorboat and a jonboat. Certainly a jonboat is an open motorboat, but it has very different characteristics from an I/O or a larger outboard powered craft. Our recommendation is that future revisions of the accident report form provide the option of identifying the type of boat as a jonboat.

Due partially to a jonboat's light weight, it is possible that it reacts more quickly and violently than a heavier fiberglass boat if it strikes a fixed rigid object. This sudden reaction could contribute to the increased likelihood that the occupants will fall out or be thrown overboard.

4.7.1.4 Common Objects Struck

It is only natural to wonder for CWFXO accidents, what it is that everyone seems to be running into. The objects struck fall into two categories. The first, consists of fixed rigid objects that are easily visible and identifiable, at least in good daylight and good weather. These include such things as docks, bridge pilings, trees, and channel markers. The second category includes objects which we may never be able to clearly identify. Officers, boat operators, and boat passengers claim that they are mostly stumps, with the occasional rock, tree root, or submerged log thrown in for variety. In most cases these objects are never seen. In a typical scenario, the boat is traveling at planing speed or better, and hits an unknown object, generally identified as a stump, throwing everyone into the water. For the sake of discussion, we will classify these two categories of objects as Above Water (AW) and Underwater (UW) objects. They could also be called visible and invisible objects as well, since the latter are almost never seen!

Eleven of the collisions involved an impact with an AW object, while 10 involved an impact with an UW object. The most common UW objects struck were identified somehow as stumps. The narratives generally indicated that the objects were never seen. Therefore, the identification of the object struck is most likely an assumption rather than a proven fact. Submerged rocks ranked as the second most common UW object struck.

Ten of the collisions were with AW objects. It appears that most anything that a boat operator can get to is a possible target. Some of the objects struck included a pier, tree, tree limb, bridge piling, oil platform, cement marker, canal gate, boat dock, and a boat house.

4.7.2 Outboard Powered Boats at Risk?

When the four canoes and one raft were subtracted from the CWFXO database, we were left with sixteen accidents. All sixteen of the boats involved were open motorboats. The boats' lengths were known to range from 11 to 20 feet. Yet, 15 out of 16 (94%) of these boats were powered by outboard motors.

The data for engine types on CWAV type accidents shows a relatively even mix of I/Os and outboards, indicating that there was not necessarily an unusually high percentage of outboards at the state level for the accidents analyzed.

While it is beyond the scope of this project to attempt to conclusively determine the reasons for this trend, it certainly raises interesting questions. It is definitely a topic worthy of further study. Section 4.10 offers some possible considerations on this subject.

4.7.3 Summary of Miscellaneous Data

A summary of the data tabulated from the CWFXO accidents by other parameters is provided in this section. Refer to section 4.4.2 on CWAV accidents if you need additional details on the category meanings. The number of accidents and the condition in which it occurred follows. The numbers in parentheses correspond to the question numbers on the form in Figure 4-3.

Light (2)
night: 5
daytime: 15

Visibility (3)
good: 18
fair: 2
poor: 1

Hit and Run?
Yes: At least one

Vessel1 Type (5)
open motorboat: 16 (includes jonboats)
canoe: 4 (one was really a kayak)
other: 1 (raft)

Engine Type (7.2)
outboard: 11
I/O: 1
Unknown: 9

Estimated Speed (32)
v: 1
h: 7
m: 1
l: 6
u: 6

v = very high speed, estimated at 40 plus mph
h = high speed, on plane or 20 plus mph
m = medium speed, just below planing speed, or near hump speed but estimated below 20 mph (but more than 10 mph)
l = low speed, below hump speed, probably less than 10 mph
u = unknown

Type Impact (37)
direct impact: 0
penetrating impact: 2
glancing blow: 5
boat ran over top of object: 7
unknown: 7

The goal was to attempt to identify the seriousness of the collision by the type of impact. Each of the above terms has relevance to the severity of deceleration which the boat would have experienced during the collision. Penetrating impact means that the boat actually traveled through the object struck. For example, in the collision with a boathouse the vessel may penetrate one or more sides of the structure. A direct impact occurs when the boat strikes an object nearly straight on, and comes to a sudden and immediate stop. If the boat were on plane, a relatively high "g" deceleration might be experienced. Almost all of the impacts with an underwater object will be considered as "boat ran over the top of the object".

4.7.4 Another Common Scenario - Circling Outboards

It is not uncommon for the operator of a small boat to be thrown out or fall out, only to have the boat go into a circle and run over him afterwards. This seems to occur most frequently in small open motorboats powered by outboard motors. Several situations have been reported where the boat was seen circling with no one aboard at the time. The operator was later found washed on shore or floating some distance away. Two of the CWFXO accidents reviewed reported that the boat struck an object, threw out one or two occupants, circled, and ran over the victim. Many of the officers we worked with during our field investigations had investigated similar accidents.

4.8 Analysis of Collisions With Floating Objects (CWFLO)

Eight fatal CWFLO accidents were reviewed. Figure 4-6 summarizes the data for persons on board, fatalities, and persons thrown overboard. The data was carefully analyzed. Significant results are summarized as follows:

1. Fifteen of the 20 occupants involved in these accidents were thrown from the boat.
2. In seven of the eight accidents, the boat was assumed to have struck a floating object. The object was never seen or located.
3. Two of the eight accidents involved small jonboats.
4. At least seven of the eight accidents involved outboard boats.

We will look briefly at these in more detail.

4.8.1 Number of Persons Thrown Overboard

There were a total of 20 occupants involved in these eight accidents. At least 15 of those 20 (75%) were thrown overboard. This is the highest incident rate of occupants being thrown overboard of the three types of collisions. These accidents accounted for a total of eight fatalities, one in each accident. The cause of death was reported as drowning for six of the eight victims. Cause of death for the other two was not reported. No information was reported on any of the six who drowned to establish if they were wearing a PFD.

4.8.2 The Unknown Object

In seven of the eight accidents, the actual object struck was never seen or positively identified. The object struck was often just assumed to be a floating log. One accident involved a boat striking a floating buoy. This was the only accident where the object struck was accurately identified. In three of these accidents, only one occupant was on board. The accident reports for all three presumed that the boat must have struck an object and thrown the operator out. The logic seems to be that "He must have hit something, why else would the operator have fallen out and drowned?"

The assumptions made and lack of evidence to support the events that actually took place makes it difficult to determine if this category of accidents is accurately coded. At least three of these accidents could just as easily have been coded as a "Falls Overboard" type accident.

4.8.3 More Jonboats

Since we noted the frequency of accidents involving jonboats in CWFXO collisions, it is worthwhile to continue this analysis in this section for CWFLO accidents. Two accidents involved 14 foot aluminum jonboats. In the first, a jonboat with two occupants struck a buoy. Both men were thrown out, and one was still missing at the time the report was filed. In the second jonboat accident the occupant fell out and drowned. The investigating officer assumed that the boat hit something, which caused the occupant to fall out.

4.8.4 For Outboards Only?

Outboard powered boats of varying lengths comprised an surprisingly large percentage of the boats involved in accidents in this category. The length of boats involved in CWFLO accidents ranged from 14 to 19 ft, and yet at least seven of the eight boats were powered by outboard motors. There was not sufficient data available to attempt to explain why, but it is an item worthy of consideration of future study. These trends are consistent with those reported in section 4.7.2 on CWFXO accidents.

4.8.5 Miscellaneous Data

A summary of the data tabulated from the CWFLO accidents by other parameters is provided in this section. Refer to the section on CWAV if you need additional details on the category meanings. The number of accidents and the condition in which it occurred follows. The numbers in parentheses correspond to the question numbers on the form in Figure 4-3.

Light (2)
night: 2
daytime: 4
unknown: 2

Visibility (3)
good: 6
unknown: 2

Hit and Run?
Yes: None

Vessel #1 Type (5)
open motorboat: 7
unknown: 1

Engine Type (7.2)
outboard: 7
I/O: 0
Unknown: 0

Estimated Speed (32)
v: 2
h: 2
m: 0
l: 0
u: 4

v = very high speed, estimated at 40 plus mph
h = high speed, on plane or 20 plus mph
m = medium speed, just below planing speed, or near hump speed but estimated below 20 mph (but more than 10 mph)
l = low speed, below hump speed, probably less than 10 mph
u = unknown

Type Impact (37)

Type of impact could generally not be established with any degree of confidence for of these accidents.

4.9 A Word About Alcohol

The data found on the reports can be viewed with varying degrees of accuracy on the subject of alcohol. Few operators will incriminate themselves by indicating on the reports they fill out that they were drinking or intoxicated at the time of the accident. They will happily point out that the other operator probably was. Investigating officers' reports are likely to be much more accurate concerning this issue when they are available. We were not able to obtain an investigating officer's report for every accident. Thus, a serious and detailed analysis of the role of alcohol in these accidents would likely be misleading. Accident reports suggested that alcohol may have been a factor for at least 11 of the 54 accidents.

4.10 Possible Reasons for High Numbers of Outboards in Accidents

One must first remember that the detailed review of the 54 accidents covered in this chapter deals only with fatal accidents. Thus, we still do not know what the ratio of outboards to I/Os is for all collision type accidents which would include non-fatals. The majority of boats involved in CWFXO and CWFLO accidents are outboard powered. This disparity does not apply to all three accident types however. For CWAV accidents, the number of I/Os is roughly the same as the number of outboards. Thus it is significant that it is only in the CWFXO and CFWLO categories that this trend appears.

As a group, outboard powered boats are lighter weight and smaller than their I/O counterparts. There is a definite relationship between the size of the boat and the risk of fatalities during a collision with a fixed or floating object. The smaller, lighter boats will tend to react more violently during an

impact than a heavier, more massive boat with all other factors being equal. A violent rapid deceleration or acceleration in almost any direction can easily throw a person out of the boat. Note that more persons were known to have been thrown out of their boats in CWFLO and CWFXO accidents than for CWAV accidents. This fact alone increases the chances for the number of fatalities due to drownings for CWFLO and CWFXO accidents.

A second consideration is that the torque steer generated by many outboards is a phenomenon not expected by some operators. This characteristic can result in an outboard traveling on plane to suddenly go into a hard turn if the steering wheel is released. To the novice boat operator, this is not what is expected. After all, the operator may deliberately let go of the wheel of an automobile just to see if the front end is still aligned! If the boat hits a stump or other object, the jolt from the impact may not be that severe. However, if the impact is sufficient to cause the operator to let go or loose the grip on the steering wheel, the boat may go into a hard turn, thus throwing the operator out of the boat. It is difficult to determine in these accidents if the occupant was thrown out of the boat directly because of the impact, or because the operator lost the grip on the wheel and the boat suddenly went into a turn.

A slightly different phenomenon can occur on small outboard powered boats with tiller steering, such as jonboats. The operator generally has a firm grip on the tiller and sits at the rear of the boat to steer. When the boat strikes an object such as a stump, the operator can lose his balance or slide to one side. At this point, two scenarios are possible. If the operator is holding on to the tiller, the boat may go rapidly into a hard turn. This event can throw the operator off balance. The boat is now literally turning out from under him, tossing him over the side of the boat. The tendency will be for the operator to fall over the side of the boat nearest the inside of the turn. The other possibility is that after striking the object, the operator slides to one side, holds onto the tiller and falls to the outside edge of the boat. In this situation, the boat may heel to the outside, much like a car traveling around a corner. The heel to the outside, coupled with the lateral acceleration experienced by the operator due to the turn, may combine to throw the operator out (toward the outside of the turn). The motor is left running, turned hard to one side, and the risk that the boat will go into a circle and strike the operator is now present.

Boat operators, especially novices, do not stop to think about how their machine differs from the car they regularly drive, or about how much different the marine environment differs from the familiar roadways.

Developing solutions to the above problem will be a difficult and, no doubt, a controversial task. Developing the best solutions may require more detailed and broad based information than that presented here. The possible range of solutions falls into two forms, active and passive solutions. The active solutions require

the operator to take some affirmative action, while the passive solutions are designed into the boat and perform a certain function without action on the operator's part.

The simplest active solutions might involve kill switches and PFDs. No doubt many deaths in CWFXO and CWFLO accidents could be prevented if only the occupants wore their PFDs. Kill switches, which technology already makes available, may lower the number of incidents of boats circling and striking the occupants after they fall overboard. PFDs are available to any boater, and kill switches are becoming commonplace. Neither is effective if the operator fails to use them.

Passive solutions might be to develop outboards so that the operator must always have contact with the throttle in order for it to remain in a forward position when the boat is in gear. That way when an operator falls out, he loses contact with the throttle, and the boat slows to idle. Of course a kill switch could accomplish the same objective, but only if the operator uses it. Another consideration might be to require that boats be self centering. This could be accomplished a number of ways, but the concept would be that if a person momentarily lost his grip on the steering wheel, that the boat does not enter into an immediate hard turn. This concept would almost certainly need to be implemented with either kill switches or a similar concept. A boat traveling straight down the channel at full throttle with no one at the controls would cause a greater hazard to other boats than one going in a circle.

No doubt there are many advantages and disadvantages to any of these concepts. The purpose of this section was not to recommend a particular solution, but to offer solutions that could be considered.

4.11 Comments on the Current Accident Reporting System

The current system of reporting and recording boating accident data leaves much room for improvement. The importance of obtaining good reliable accident data and providing a meaningful analysis of that data cannot be over emphasized. This is the information that drives the system. Laws, regulations, recommended practices and voluntary standards are all created and shaped in an effort to correct or minimize whatever it is that is identified as a problem.

Rather than provide a lengthy discussion of all the problem areas encountered, we have provided a series of recommendations that should be considered when reviewing the current accident reporting system. Many of these recommendations, in theory, represent current practice, but are repeated here because reality is dramatically different! The following summarizes the recommendations regarding accident reporting and recording based on our experiences handling the data.

4.12 Problems and Recommendations:

1. Place more emphasis on the data provided by the investigating officer and less by the boat operator for all accidents where this is possible.

2. Accept only the investigating officer's data for input into the accident database for fatal accidents.

3. Conduct a review of fatal accident reports when they are submitted by the state. If the report is incomplete or of unacceptable quality, the report should be sent back to the state to be properly completed.

4. Develop a system for accurately recording injury types, location, severity, and possible causes (if known) for fatal and non-fatal accidents. Current accident reports provide insufficient information on injuries for both fatal and non-fatal accidents.

5. Record the location of the occupants in each boat just prior to the accident.

6. Record the number of persons on board, where they were seated before the accident, and which occupants were thrown overboard. At a minimum, the no. of persons on board, and the number of persons thrown overboard should be documented.

7. Record the cause of death for all fatalities. Cause of death due to injuries should be clearly distinguished from drownings.

8. If cause of death was drowning, indicate if the person was wearing a PFD. If the person was wearing a PFD, note the type, size, and condition of the PFD. The following questions should be answered:
    - Was the person conscious just prior to drowning?
    - Did hypothermia lead to the drowning?

9. Provide a simple diagram of the collision and a narrative of what happened.

10. Fill in all of the applicable information on the current USCG accident report form.

11. Provide training and training materials to accident investigators explaining the report forms and what information is required in each block.

12. Develop a special form for collision accidents that contains information blocks for both boats involved.

13. Develop means to record damage to boats and injuries to occupants. (The state of Missouri has done an excellent job of developing forms in this area).

14. Provide meaningful analyses to look for trends and common denominators using more detailed data similar to that conducted in this chapter.

15. Add jonboat as one of the boat types on the form.

16. Add inflatable as one of the boat types on the form.

REPORT DATE 05/13/91

FATAL COLLISIONS 1990

USCG 10513V

AUXILIARY, BOATING, & CONSUMER AFFAIRS G-NAB

WASHINGTON, DC 20593-0001 (202) 267-0955

CASE #	J R	AGE OPR	E X	RE NT	# POB	I N	MIC	B T	H M	E NG	HP	LE NG	YR BU	DATE ACCDNT	TI ME	TYP WAT	ST	COU NTY	W R	W C	TE MP	WI ND	V S	OP ER	ACCTYP #1#2#3	P FD	$/100 DAMGE	# DRO	# VIC	# INJ	# VES	CAUSES #1#2#3	DESCRIPT #1#2#3#4	#
02036	1	99	9	9	02	9	UUU	1	9	9	999	18	99	080890	99	3	AK	040	9	9	9	9	9	99	010210	9	$ 0	2	0	0	1	99	95	1
05222	1	52	9	2	02	9	DMB	1	4	1	400	18	80	071390	99	4	CA	107	1	2	5	1	1	10	011012	9	$ 5	0	1	0	1	34	59 97	1
12833	2	35	1	2	03	5	SER	2	4	3	332	36	79	061090	22	5	FL	087	2	1	7	1	5	10	0112	2	$ 5	1	0	0	1	25	60 96	1
12853	1	68	2	2	02	5	OMM	1	4	1	085	18	89	083090	01	1	FL	101	1	1	7	2	4	10	01	2	$ 0	1	0	0	1	25	96	1
21075	1	30	1	2	01	5	YAM	J	4	2	040	10	89	082590	20	5	KY	231	1	1	7	0	5	10	01	1	$ 10	0	1	0	1	2122	96	1
24189	2	53	2	2	02	5	UUU	2	4	2	120	16	80	070490	14	4	MD	015	2	2	9	3	1	60	0110	2	$ 0	1	0	0	1	21	48 96	1
41182	2	23	4	2	01	6	UUU	1	4	2	998	18	89	092290	19	5	NC	179	1	1	7	0	1	20	01	2	$ 470	0	1	0	1	39	97	1
36019	1	59	9	2	02	9	SER	2	4	4	260	25	87	032990	17	3	NJ	011	1	3	3	2	2	10	01	2	$ 50	0	1	0	1	42	96	1
43110	1	45	4	2	06	2	CTY	3	4	3	007	27	74	090690	20	2	OH	035	2	4	6	4	5	10	010810	2	$ 165	3	0	3	1	10	97	1
48107	2	55	2	2	02	5	XXX	1	1	1	090	23	87	091790	11	5	SC	013	1	1	6	1	1	61	010304	2	$ 30	2	0	0	1	2125	96	1
56056	1	66	9	2	01	9	UUU	2	1	2	999	32	27	062290	99	1	WA	049	4	3	9	9	3	10	010210	2	$ 10	1	0	0	1	10	97	1
																											$ 745	11	4	3				11

Figure 4-1 (page 1)

USCG AUXILIARY, BOATING, & CONSUMER AFFAIRS G-NAB
10513V WASHINGTON, DC 20593-0001 (202) 267-0955

CASE #	J R	AGE OPR	E X	RE NT	# POB	I N	MIC	B T	H M	E NG	HP	LE NG	YR BU	DATE ACCDNT	TI ME	TYP WAT	ST	COU NTY	W R	W C	TE MP	WI ND	V S	OP ER	ACCTYP #1#2#3	P FD	$/100 DAMGE	# DRO	# VIC	# INJ	# VES	CAUSES #1#2#3	DESCRIPT #1#2#3#4	#
04035	2	99	9	9	99	9	UUU	9	9	9	999	99	99	050890	20	5	AR	107	1	1	4	1	2	10	071012	9	$ 0	0	1	0	2	32	97	1
05228	1	36	9	2	07	9	TNR	1	4	1	351	19	99	071490	99	3	CA	077	1	1	9	1	2	30	07	9	$ 80	0	1	4	2	32	97	1
05224	1	30	9	2	03	9	HND	1	4	5	999	99	71	072190	99	4	CA	107	1	1	5	1	1	10	07	9	$ 0	0	3	0	2	2842	96	1
05263	2	25	9	9	01	9	UUU	J	4	5	999	99	99	080190	99	5	CA	065	1	2	4	1	2	10	07	9	$ 0	0	1	0	1	21	96	1
05468	2	32	9	1	03	9	GRE	1	2	1	006	14	90	081190	19	5	CA	065	1	1	7	1	1	10	07	9	$ 0	0	1	1	2	32	97	1
05299	2	22	9	2	01	9	KAW	J	4	5	999	07	99	081990	99	5	CA	037	1	2	6	3	1	20	07	1	$ 0	0	1	0	2	32	97	1
05352	2	36	2	2	03	9	XMG	1	4	4	120	18	73	082590	15	3	CA	077	1	1	5	1	1	30	07	9	$ 0	1	0	1	2	23	97	1
05353	2	60	4	2	05	1	JAY	1	4	1	235	20	79	082590	12	4	CA	077	1	2	5	1	1	10	07	1	$ 75	0	1	3	2	32	97	1
12811	1	59	9	2	04	9	LBL	1	4	1	085	17	81	020990	08	4	FL	127	1	1	9	9	1	10	07	2	$ 26	3	0	1	3	25	96	1
12819	1	47	9	1	01	5	YAM	J	4	5	999	09	90	041290	18	3	FL	071	1	1	6	9	1	10	0712	1	$ 0	0	1	0	2	32	60 97	1
12829	1	32	9	1	03	5	PPJ	2	9	1	200	21	87	052090	01	3	FL	011	2	1	7	1	5	10	071012	2	$ 0	1	0	2	1	28	98	1
12830	1	35	9	2	01	9	YAM	J	4	5	999	99	89	052790	02	4	FL	095	2	1	6	0	5	10	0712	0	$ 40	0	1	0	2	2521	59 96	1
12832	2	17	2	2	01	6	YAM	J	4	5	032	09	90	053190	13	3	FL	091	1	1	7	0	1	10	07	1	$ 2	0	1	0	2	21	96	1
12848	2	45	4	2	05	5	GSY	1	4	4	185	15	87	082690	16	5	FL	025	1	2	6	1	1	10	071012	2	$ 9	0	1	1	2	32	96	1
12860	1	47	3	2	02	9	KAW	J	4	5	055	09	90	100790	16	3	FL	025	1	2	7	3	1	10	07	1	$ 8	0	1	1	2	32	97	1
12874	2	21	9	2	01	9	KAW	J	4	5	029	07	87	122790	14	5	FL	103	9	9	9	9	9	10	07	1	$ 0	0	1	0	2	25	96	1
14018	2	18	3	2	04	9	AST	1	4	1	115	16	79	042590	15	5	GA	139	1	1	5	1	1	10	07	2	$ 0	1	0	3	2	25	48 96	1
16076	2	32	4	2	04	1	4WN	1	4	4	175	18	89	072890	17	5	ID	045	1	1	9	1	1	30	0713	2	$ 0	0	1	0	2	32	53 97	1
17056	2	32	4	2	05	6	PLR	1	2	1	055	20	72	070490	23	5	IL	139	1	2	7	2	5	10	0710	2	$ 20	1	0	1	2	2821	96	1
17084	2	36	9	2	04	9	CRL	1	4	1	115	17	77	072490	23	5	IL	085	1	1	6	0	5	60	07	2	$ 20	0	1	3	2	29	96	1
17089	1	39	9	2	02	9	SER	1	4	4	999	18	90	081190	18	4	IL	063	1	2	9	1	1	10	07	2	$ 0	0	2	0	2	2721	96	1
17108	1	33	9	2	06	9	LUN	9	9	9	999	99	76	081890	23	4	IL	031	9	9	9	9	9	60	07	9	$ 0	1	0	0	1	41	98	1
17111	1	45	4	2	02	5	BNT	1	4	4	130	17	90	090290	15	4	IL	057	1	5	7	1	1	60	07	2	$ 0	0	1	0	1	32	98	1
21045	1	42	4	2	05	9	UUU	1	4	1	070	15	79	070790	23	5	KY	027	1	3	7	1	5	10	07	2	$ 15	1	0	1	2	32	39 97	1
21066	1	99	9	9	05	9	UUU	9	9	9	999	99	99	072890	19	5	KY	207	1	1	7	1	1	10	0710	9	$ 0	1	0	2	2	27	96	1
21085	1	99	3	2	04	9	CHK	1	4	4	330	22	89	081090	24	4	KY	037	1	1	9	1	5	10	07	2	$ 250	0	1	3	2	2825	96	1
21074	1	59	9	2	02	9	SSB	1	4	4	170	18	84	090490	17	5	KY	207	1	1	7	1	1	10	07	1	$ 10	0	1	0	2	32	97	1
22034	1	26	4	2	01	5	UUU	2	2	1	180	23	82	041090	22	3	LA	099	2	1	5	1	5	10	07	2	$ 20	0	1	0	2	2821	96	1
22078	1	48	4	2	02	4	SDP	1	4	1	080	16	70	051690	18	3	LA	051	1	1	9	9	1	20	0710	1	$ 0	1	0	0	1	32	98	1
22058	2	77	4	2	02	1	DUA	1	4	1	025	14	99	062690	12	5	LA	079	1	1	9	0	1	20	07	1	$ 15	0	1	1	2	42	96	1
26015	2	45	1	2	04	5	UUU	1	4	4	140	16	85	070390	22	5	MA	017	1	1	6	1	5	10	07	0	$ 25	0	1	3	2	32	97	1
26075	2	99	9	9	02	9	UUU	1	2	1	002	12	99	091690	16	5	MA	027	1	1	9	0	1	10	07	9	$ 0	0	2	0	2	32	97	1
24144	1	20	9	2	09	9	WEL	2	4	4	270	23	88	091690	01	4	MD	017	1	1	9	1	5	10	07	2	$ 250	0	1	3	1	29	48 98	1
27005	1	99	9	2	02	9	XDC	1	4	1	040	13	89	070390	15	2	MI	139	1	2	6	2	1	10	07	2	$ 5	0	1	1	1	32	97	1
27158	1	23	9	2	01	9	KAW	J	4	9	999	07	88	080490	17	4	MI	115	1	1	6	1	1	50	07	9	$ 15	0	1	0	2	212542	96	1
27276	1	36	9	2	05	9	AGC	2	4	4	007	24	88	090190	23	4	MI	115	1	1	6	1	4	10	07	2	$ 120	0	1	0	2	21	48 96	1
29001	1	31	1	2	02	5	AGC	1	4	1	150	18	75	042290	18	4	MN	123	1	2	4	2	1	10	07	2	$ 25	0	1	1	2	32	97	1
31136	2	21	2	2	12	5	MBC	2	4	4	454	24	89	072990	22	5	MO	029	2	2	7	2	5	60	0712	9	$ 70	0	1	0	2	32	97	1
30014	1	18	9	1	01	9	YAM	J	4	5	999	07	89	041590	16	3	MS	047	1	1	4	1	1	10	07	1	$ 2	0	1	0	2	32	97	1
30057	2	30	2	2	01	5	ZZN	J	4	2	999	08	89	072190	13	5	MS	141	2	2	7	1	1	10	07	1	$ 12	0	1	0	2	2925	96	1
30071	1	24	9	9	01	9	UUU	9	9	9	999	99	99	090190	23	4	MS	045	1	1	7	0	5	60	07	9	$ 1	0	1	0	2	29	96	1
41083	2	42	4	2	03	5	MFG	1	4	1	050	15	73	060990	19	4	NC	023	4	2	4	3	3	10	0710	2	$ 16	1	0	2	2	1022	96	1
41085	2	40	3	2	03	5	THV	1	4	1	140	15	82	061690	22	4	NC	173	2	1	5	1	6	10	0708	2	$ 20	1	1	1	2	282925	96	1
41111	1	16	2	2	02	5	YAM	J	4	2	043	09	90	070890	16	4	NC	123	1	2	8	1	1	10	071012	2	$ 4	0	1	0	2	214225	5960 96	1
41164	1	17	9	1	01	9	KAW	J	4	2	030	07	88	080990	18	3	NC	055	2	1	6	1	1	10	0712	1	$ 40	0	1	0	2	25	59 96	1
41185	1	36	9	2	02	9	GSY	1	4	1	115	17	89	092990	13	4	NC	015	1	1	7	1	1	10	0712	1	$ 50	0	1	1	2	232825	96	1
35010	2	38	4	2	04	9	HNR	1	4	1	999	21	83	051290	17	5	NH	011	1	9	9	9	1	10	07	9	$ 0	1	0	0	2	32	97	1
36194	1	21	3	2	01	5	KAW	J	4	5	999	07	89	072590	18	4	NJ	025	1	1	6	1	1	10	07	9	$ 0	0	1	0	1	4227	96	1
34095	1	28	9	2	01	9	UUU	J	4	9	999	99	99	090190	14	4	NV	003	1	2	4	2	1	10	07	9	$ 0	0	1	0	2	2731	96	1
39102	1	38	2	2	02	5	XTC	6	1	7	000	16	99	080990	22	5	NY	097	1	1	5	1	5	60	0712	2	$ 5	0	1	0	2	29	59 96	1
43017	1	25	1	2	01	6	SER	1	4	4	999	20	84	052890	02	2	OH	123	2	1	5	1	5	10	07	2	$ 100	1	0	0	2	42	48 96	1
43060	1	27	3	2	04	9	9ZF	2	4	4	330	23	88	061590	24	2	OH	123	1	1	5	0	5	10	07	1	$ 120	0	1	3	2	32	97	1

Figure 4-1 (page 2)

REPORT DATE 05/13/91

FATAL COLLISIONS 1990

USCG
10513V

AUXILIARY, BOATING, & CONSUMER AFFAIRS G-NAB
WASHINGTON, DC 20593-0001 (202) 267-0955

CASE #	J R	AGE OPR	E X	RE NT	# POB	I N	MIC	B T	H M	E NG	HP	LE NG	YR BU	DATE ACCDNT	TI ME	TYP WAT	ST	COU NTY	W R	W C	TE MP	WI ND	V S	OP ER	ACCTYP #1#2#3	P FD	$/100 DAMGE	# DRO	# VIC	# INJ	# VES	CAUSES #1#2#3	DESCRIPT #1#2#3#4	#
43060	1	25	9	2	04	9	SB2	2	4	4	100	20	89	061590	24	2	OH	123	1	1	5	0	5	10	07	2	$ 100	0	2	2	2	27	96	1
44052	1	15	2	2	04	9	SER	1	4	4	235	18	80	081190	22	5	OK	013	1	1	7	1	5	10	07	9	$ 90	2	0	2	2	32	97	1
45085	1	23	9	9	01	9	UUU	J	4	5	999	99	99	092390	12	4	OR	053	1	5	5	1	1	10	07	1	$ 0	0	1	0	2	25	96	1
63007	1	50	3	2	03	9	MZB	2	4	1	040	16	75	040690	02	1	PR	072	1	2	6	2	5	70	07	2	$ 8	1	0	0	2	29	98	1
48080	1	24	2	2	04	5	GLA	1	4	1	090	17	78	051990	18	5	SC	081	1	1	5	1	1	10	07	2	$ 14	0	1	1	2	32	97	1
48054	2	33	2	2	14	6	KQU	0	2	1	075	24	87	063090	23	5	SC	063	1	1	7	1	5	10	07	2	$ 30	0	1	0	2	21	96	1
48097	1	42	9	2	01	9	YAM	J	4	2	999	09	88	082690	18	5	SC	007	1	1	7	0	1	10	07	2	$ 0	0	1	0	2	2125	96	1
50012	1	99	9	9	02	9	UUU	9	9	9	999	99	99	042590	15	5	TN	057	1	2	9	1	1	10	07	9	$ 0	1	0	0	1	32	97	1
50079	2	24	4	2	02	5	MDT	1	4	1	150	17	81	063090	01	5	TN	051	1	1	7	1	4	10	07	2	$ 85	0	2	0	2	32	97	1
50998	1	99	9	9	99	9	CHE	2	4	1	999	17	99	072490	22	5	TN	089	9	9	9	9	9	99	07	9	$ 0	2	0	0	2	99	95	1
51108	2	68	9	2	02	9	UUU	9	9	9	999	99	99	062790	99	5	TX	113	9	9	9	9	9	60	07	9	$ 0	0	1	0	2	32	97	1
51149	2	27	3	2	03	5	EVN	1	4	1	115	16	67	063090	23	5	TX	503	1	3	7	1	5	10	071012	2	$ 15	0	1	1	2	292521 59	96	1
51212	2	20	1	2	03	5	UUU	1	2	1	002	12	99	071490	23	5	TX	339	1	1	7	1	5	10	070210	0	$ 10	0	1	1	2	2129	96	1
53029	2	48	4	2	06	9	HYD	1	4	1	125	17	65	073090	20	5	UT	043	1	1	6	9	1	30	070210	2	$ 20	2	0	2	2	21	96	1
55047	1	15	2	2	01	5	YAM	J	4	5	999	09	99	072690	20	5	VA	155	1	1	7	0	1	10	07	1	$ 10	0	1	0	2	42	96	1
59076	2	21	9	9	01	9	UUU	J	4	5	999	99	99	060590	20	5	WI	063	1	1	6	0	5	10	07	9	$ 0	0	1	0	2	25	96	1
59114	2	45	9	2	01	9	UUU	4	4	6	000	09	99	062390	15	5	WI	025	1	4	9	4	1	13	07	9	$ 10	0	1	0	2	32	97	1
58003	2	99	9	9	99	9	UUU	9	9	9	999	99	99	051490	19	4	WV	039	1	1	3	0	1	60	07	9	$ 2	1	0	0	1	2125	98	1
																											$1864	24	58	67				70

Figure 4-1 (page 3)

USCG 10513V AUXILIARY, BOATING, & CONSUMER AFFAIRS G-NAB
WASHINGTON, DC 20593-0001 (202) 267-0955

CASE #	J R	AGE OPR	E X	RE NT	# POB	I N	MIC	B T	H M	E NG	HP	LE NG	YR BU	DATE ACCDNT	TI ME	TYP WAT	ST	COU NTY	W R	W C	TE MP	WI ND	V S	OP ER	ACCTYP #1#2#3	P FD	$/100 DAMGE	# DRO	# VIC	# INJ	# VES	CAUSES #1#2#3	DESCRIPT #1#2#3#4		#
01042	1	20	9	2	03	9	BUJ	1	4	1	150	17	87	051990	15	4	AL	099	1	1	6	1	1	10	08	9	$ 50	0	1	2	1	2825	48	96	1
01071	2	27	2	2	05	5	LAR	1	4	2	160	19	82	061790	16	5	AL	133	1	1	6	0	1	30	08	2	$ 0	0	1	0	1	25		97	1
01083	2	49	3	2	08	5	ELD	1	4	1	100	17	72	070190	20	5	AL	087	1	1	7	1	5	20	0810	2	$ 0	1	0	0	1	2823	48	96	1
01106	1	19	3	2	02	5	ELD	1	4	4	165	18	72	072790	15	5	AL	033	1	1	6	0	1	30	08	2	$ 0	0	1	0	1	98	53	97	1
04004	2	27	9	2	04	9	UUU	7	5	7	000	99	99	042190	17	5	AR	115	1	5	4	1	1	60	0810	1	$ 0	1	0	0	1	3342		96	1
08036	2	50	4	2	01	6	XXX	6	4	7	000	12	99	061190	16	4	CO	097	1	5	3	1	1	60	08	1	$ 0	1	0	0	1	98		97	1
12801	1	41	4	2	04	2	ASP	1	4	1	040	20	88	010790	19	3	FL	025	1	1	6	1	4	10	0810	2	$ 80	1	0	3	1	21		96	1
12814	2	29	2	2	04	5	UUU	2	4	1	100	20	71	022190	17	4	FL	011	2	1	6	2	1	10	0810	0	$ 20	1	0	0	1	25	16	96	1
12815	1	53	3	2	02	9	MEL	2	4	4	999	22	88	030390	21	4	FL	057	1	9	4	0	5	10	0810	9	$ 0	1	0	1	1	28		96	1
12827	2	24	2	2	06	5	AGC	1	4	1	115	17	83	042290	16	5	FL	055	1	1	9	9	1	30	08	9	$ 0	0	1	0	1	21	49	96	1
12822	1	26	3	2	04	5	CBA	1	4	1	150	18	80	043090	01	5	FL	031	3	1	9	1	5	10	08	2	$ 67	0	4	0	1	2825	48	96	1
12828	2	27	1	2	05	5	JCO	1	4	1	115	17	87	051890	22	4	FL	081	9	9	9	9	9	10	0810	0	$ 20	2	0	3	1	2125		96	1
12844	1	27	9	2	02	9	RXN	1	4	1	200	19	90	072290	04	3	FL	025	1	1	9	9	5	10	08	2	$ 100	0	1	1	1	2128		96	1
12845	2	26	4	2	03	5	AVB	1	5	1	025	13	90	081690	03	5	FL	091	1	1	7	0	5	10	08	2	$ 10	1	0	0	1	21	48	96	1
12849	1	30	9	2	02	9	KAH	J	4	5	999	09	90	082590	18	4	FL	009	2	2	9	2	1	10	08	1	$ 3	1	0	1	1	4225	48	96	1
12852	1	39	9	2	04	9	MRK	1	4	1	150	19	90	082690	21	1	FL	099	1	1	9	9	5	10	08	9	$ 100	0	1	1	1	2128		96	1
12857	2	32	4	2	03	5	UUU	1	4	1	150	20	72	092090	20	5	FL	031	1	1	7	1	1	10	08	2	$ 34	2	0	1	1	28	48	96	1
12873	2	52	9	1	01	5	UUU	0	2	8	999	12	86	121090	99	4	FL	017	1	1	6	1	1	10	08	2	$ 8	0	1	0	1	28	4829	96	1
14007	2	41	3	2	02	5	BUJ	1	2	1	050	16	99	031790	01	4	GA	049	1	1	9	0	5	10	08	2	$ 0	0	1	1	1	23		96	1
14026	1	32	3	2	02	5	XXX	1	2	1	020	14	99	051390	15	4	GA	191	1	1	9	1	1	10	081004	2	$ 2	1	0	0	1	24		97	1
19016	1	75	3	2	03	9	UUU	1	4	1	100	17	64	072690	16	4	IA	097	2	2	6	3	1	10	08	1	$ 0	1	0	0	1	4210		96	1
19034	1	99	4	2	08	9	AGC	1	4	1	150	18	78	080590	11	4	IA	043	1	2	6	2	1	10	08	9	$ 0	1	0	3	1	28		96	1
16075	2	36	9	2	03	9	UUU	7	5	7	000	99	99	060190	14	4	ID	049	9	5	9	9	1	60	080210	1	$ 0	0	1	0	1	33	28	97	1
16046	2	41	3	2	05	5	UUU	7	5	7	000	99	76	072990	15	4	ID	043	1	4	5	1	1	60	080210	1	$ 0	1	0	1	1	2433		97	1
17016	2	35	2	2	02	5	UUU	6	4	7	000	99	99	052790	14	4	IL	201	1	5	9	1	1	60	080210	2	$ 0	1	0	0	1	21		96	1
21011	2	42	3	2	09	5	JBE	9	9	9	145	16	77	051590	17	5	KY	071	2	1	5	1	1	10	081012	0	$ 10	1	0	0	1	31	60	96	1
21090	2	31	2	1	02	6	XLU	6	2	7	000	16	75	061690	14	5	KY	073	1	5	6	1	1	60	08	1	$ 0	1	0	1	1	33	0728	97	1
22115	1	13	2	2	02	5	MRB	1	4	1	085	16	76	061290	20	4	LA	109	1	1	6	1	1	30	08	2	$ 0	0	1	0	1	21		96	1
22075	2	21	1	2	07	5	AGC	1	4	1	140	16	82	063090	20	4	LA	077	2	1	8	1	1	10	08	2	$ 8	0	1	3	1	2821		96	1
22998	1	85	9	9	02	9	UUU	9	1	9	999	99	99	071990	99	5	LA	057	9	9	9	9	9	11	0810	9	$ 0	0	1	0	1	99		95	1
22995	2	12	9	9	03	9	UUU	9	2	9	999	14	99	072290	19	5	LA	099	9	9	9	9	9	99	080210	9	$ 0	0	1	2	1	99		95	1
22103	2	43	9	2	02	9	SHK	1	4	1	115	15	90	081390	04	4	LA	063	1	1	6	1	4	99	08	9	$ 0	0	2	0	1	24		95	1
22116	2	67	3	2	02	5	UUU	1	4	1	090	16	71	081790	10	3	LA	075	1	1	7	1	1	10	081012	2	$ 0	0	1	1	1	24	59	97	1
22137	2	30	4	2	04	5	UUU	1	4	1	115	18	69	100690	21	5	LA	089	1	1	9	1	5	10	08	2	$ 40	0	2	2	1	22	43	97	1
22142	2	41	2	2	02	5	FCS	1	4	1	080	16	79	102890	17	5	LA	119	1	1	5	1	1	11	0810	0	$ 4	1	0	0	1	25	48	96	1
29002	1	58	4	2	01	5	ACB	1	2	1	030	14	99	042890	13	4	MN	157	4	2	4	2	1	10	08	2	$ 3	1	0	0	1	99		95	1
29107	2	29	9	2	06	9	TNR	1	4	4	260	20	80	081590	22	5	MN	047	1	1	6	1	4	10	0810	2	$ 50	0	1	0	1	2821	48	96	1
31001	1	61	2	2	02	6	CNP	1	4	1	004	11	87	022490	16	5	MO	213	1	3	2	3	1	11	080210	2	$ 0	1	0	1	1	24	48	96	1
31029	1	15	1	1	02	9	UUU	6	2	7	000	17	99	052590	12	4	MO	203	2	5	5	3	1	60	080210	9	$ 0	1	0	0	1	33		97	1
31168	2	42	3	2	02	9	AWL	1	9	1	090	18	82	082090	05	4	MO	125	1	1	7	2	1	10	081012	9	$ 0	1	0	0	1	2416		96	1
30037	2	60	2	1	02	9	ALP	5	2	7	000	14	99	062090	11	5	MS	035	2	5	9	0	1	60	08	2	$ 0	1	0	0	1	2425		96	1
30049	1	65	3	2	01	5	BNN	1	4	1	050	15	75	062690	13	5	MS	071	1	1	5	1	1	10	08	2	$ 1	1	0	0	1	24		97	1
30079	1	55	2	2	05	5	ACB	1	2	1	060	17	99	090890	16	4	MS	059	1	1	7	1	1	10	0810	1	$ 5	0	1	3	1	28		96	1
30082	1	37	4	2	02	5	SPR	1	2	1	010	14	88	091690	13	5	MS	107	1	1	6	1	1	10	0810	2	$ 3	1	0	1	1	2128		96	1
41001	1	48	1	2	02	5	TCB	1	4	1	135	21	78	011890	15	3	NC	031	1	2	3	2	1	10	0810	2	$ 12	1	0	1	1	4221		96	1
41076	2	20	2	2	04	5	SYL	1	2	1	050	28	87	041590	19	4	NC	003	1	1	5	1	1	10	08	2	$ 0	0	1	0	1	98		97	1
41096	2	36	2	2	02	5	BLB	1	4	1	125	19	89	070490	14	5	NC	057	1	2	7	1	1	30	08	1	$ 0	0	1	1	1	28		96	1
41097	2	26	4	2	03	5	VNB	1	4	1	090	15	80	070490	14	5	NC	123	1	2	7	1	1	10	081312	2	$ 1	0	1	0	1	21	59	96	1
39153	1	27	2	2	04	9	RXS	2	4	4	330	22	89	052690	02	4	NY	045	1	5	5	1	5	10	08	2	$ 240	0	2	2	1	2821	48	96	1
39150	2	24	3	2	06	5	SSB	1	4	1	115	17	79	061590	20	5	NY	059	2	1	5	0	2	10	081110	2	$ 40	1	0	5	1	34		97	1
63006	1	16	1	2	02	5	UUU	J	4	2	999	99	99	053090	17	3	PR	072	1	1	6	1	1	10	08	1	$ 0	0	1	0	1	2842		96	1
48007	1	30	3	2	03	5	ELD	1	2	1	050	15	80	031790	07	5	SC	077	4	5	5	2	3	61	080210	2	$ 40	3	0	0	1	3325	29	96	1

Figure 4-1 (page 4)

REPORT DATE 05/13/91 FATAL COLLISIONS 1990 PAGE 5

USCG AUXILIARY, BOATING, & CONSUMER AFFAIRS G-NAB

10513V WASHINGTON, DC 20593-0001 (202) 267-0955

CASE #	J R	AGE OPR	E X	RE NT	# POB	I N	MIC	B T	H M	E NG	HP	LE NG	YR BU	DATE ACCONT	TI ME	TYP WAT	ST	COU NTY	W R	W C	TE MP	WI ND	V S	OP ER	ACCTYP #1#2#3	P FD	$/100 DAMGE	# DRO	# VIC	# INJ	# VES	CAUSES #1#2#3	DESCRIPT #1#2#3#4	#
48066	1	25	3	2	04	5	RNG	1	4	1	150	16	79	071590	17	4	SC	051	2	1	6	1	1	30	08	1	$ 0	0	1	0	1	24	97	1
48075	1	11	2	2	01	6	UUU	6	4	7	000	99	99	072890	16	4	SC	073	1	5	4	1	1	60	0810	1	$ 0	1	0	0	1	33	57 97	1
48071	1	35	2	2	02	5	LWN	1	2	1	020	14	78	072990	17	4	SC	053	1	1	7	1	1	11	0810	2	$ 0	1	0	0	1	2125	96	1
50001	2	32	3	2	02	5	UUU	6	2	7	000	19	99	010190	13	4	TN	059	1	5	2	2	1	62	080210	2	$ 0	1	0	0	1	3342	48 96	1
50036	2	69	3	9	02	9	UUU	1	2	1	999	99	99	070990	99	5	TN	097	9	9	9	9	9	61	081012	2	$ 0	0	1	1	1	25	59 96	1
51004	2	72	9	2	01	9	UUU	1	4	1	055	16	99	021990	16	5	TX	315	1	1	4	2	1	10	0810	1	$ 1	0	1	0	1	24	16 96	1
51007	2	74	2	2	02	5	STE	1	4	1	070	16	75	022490	20	5	TX	213	1	2	4	1	1	10	08	2	$ 30	0	1	1	1	2428	96	1
51168	2	38	4	2	02	5	DUA	1	2	1	015	12	99	022690	15	5	TX	297	2	4	4	4	2	61	080210	2	$ 0	1	0	0	1	10	97	1
51018	2	14	1	2	03	5	SES	5	2	7	000	10	68	031290	15	5	TX	147	2	5	5	0	1	60	080210	0	$ 1	1	0	0	1	33	97	1
51071	2	49	4	2	08	5	GSY	1	4	4	260	22	89	060290	19	4	TX	251	1	1	6	1	1	30	08	1	$ 20	0	1	2	1	24	97	1
55017	1	70	9	2	02	9	CNP	1	9	1	003	12	99	060690	09	4	VA	077	1	5	9	1	1	60	080304	2	$ 0	1	0	0	1	24	96	1
55070	1	43	4	2	02	5	SER	1	4	1	050	15	67	080390	06	4	VA	710	1	1	9	2	2	10	08	2	$ 5	0	1	1	1	21	48 96	1
56093	2	50	1	2	02	5	UUU	7	5	7	000	06	99	072190	14	4	WA	067	9	2	9	9	9	60	080210	0	$ 0	1	0	0	1	42	96	1
58006	1	14	2	2	02	1	MMN	6	4	7	000	17	85	062090	16	4	WV	077	2	3	5	1	1	60	080210	2	$ 0	1	0	0	1	4233	96	1
																											$1008	40	36	46				66

Figure 4-1 (page 5)

REPORT DATE 05/13/91 | USCG 10513V | FATAL COLLISIONS 1990 | AUXILIARY, BOATING, & CONSUMER AFFAIRS G-NAB | WASHINGTON, DC 20593-0001 (202) 267-0955 | PAGE 6

CASE #	J R	AGE OPR	E X	RE NT	# POB	I N	MIC	B T	H M	E NG	HP	LE NG	YR BU	DATE ACCDNT	TI ME	TYP WAT	ST	COU NTY	W R	W C	TE MP	WI ND	V S	OP ER	ACCTYP #1#2#3	P FD	$/100 DAMGE	# DRO	# VIC	# INJ	# VES	CAUSES #1#2#3	DESCRIPT #1#2#3#4	#
02005	1	40	9	9	99	9	UUU	9	9	9	999	99	99	052590	99	4	AK	050	9	9	9	9	9	10	09	9	$ 0	1	0	0	1	21	96	1
04014	2	37	9	2	01	9	UUU	1	2	1	999	99	99	051790	99	5	AR	055	9	9	9	9	9	10	09	2	$ 0	1	0	0	1	28	96	1
04016	2	42	9	2	01	9	XMR	1	2	1	085	16	70	060890	16	5	AR	051	1	2	9	1	1	10	09	0	$ 0	1	0	0	1	24	97	1
05223	1	28	9	2	04	9	CMM	1	9	1	999	15	99	071590	99	1	CA	037	1	2	9	2	1	10	090210	2	$ 0	2	0	0	1	24	97	1
14104	1	56	9	2	02	9	FMC	1	2	1	020	14	99	121190	10	4	GA	051	1	1	5	1	1	10	09	2	$ 6	1	0	1	1	2823	96	1
17006	1	44	4	2	02	5	XXX	1	2	1	060	20	99	042590	16	4	IL	157	1	2	9	3	1	61	0910	2	$ 0	1	0	0	1	24	97	1
22004	1	24	4	2	05	5	UUU	1	2	1	150	16	82	022790	19	4	LA	109	1	2	4	2	5	10	0910	2	$ 3	1	0	3	1	2433	48 96	1
27065	2	65	4	2	01	5	SEA	1	2	1	025	14	81	042690	11	5	MI	015	1	1	3	1	1	20	090210	2	$ 0	1	0	0	1	21	96	1
39120	2	35	4	2	02	4	RAS	1	4	2	999	18	71	061690	18	5	NY	113	1	1	6	0	1	10	09	1	$ 0	0	1	0	1	24	97	1
48042	1	40	1	2	03	5	SCZ	1	2	1	005	12	68	061290	18	5	SC	017	1	1	9	1	5	10	090210	1	$ 0	1	0	0	1	2501	96	1
50004	1	53	9	2	02	5	UUU	1	4	1	020	14	99	021990	17	5	TN	013	1	1	3	1	1	11	0910	2	$ 0	1	0	0	1	24	97	1
56085	2	30	3	2	06	5	BUJ	1	4	1	150	18	88	071790	18	5	WA	025	1	1	5	0	1	10	091012	2	$ 0	0	1	0	1	24	97	1
																											$ 9	11	2	4				12
																											$3626	86	100	120				159

Figure 4-1 (page 6)

Boating Accident Report Coding Instructions

CASE#	CASE NUMBER ASSIGNED
JUR	JURISDICTION - (Alaska, New Hampshire - all waters Federal) Joint CG State/Federal - 1 State - 2 Unknown - 9 (non-fatals only)
AGE	AGE OF OPERATOR - Code age prefixing a zero if age is less than 10 Age unknown - code 99 No Operator - Code 00
EXP	OPERATORS EXPERIENCE - Code only for this type of boat No operator....0 / Under 20 hrs...1 / 20 - 100 hrs...2 / 100 - 500 hrs....3 / Over 500 hrs.....4 / Unknown..........9
RENT	RENTED BOAT Yes - 1 No - 2 Unknown - 9
POB	NUMBER OF PERSONS ON BOARD - Count all people in boat just prior to accident, code directly, if less than 10 prefix with 0. If this is coded "00", then AGE, EXP & INST are coded "0". None - 00 Unknown - 99
INST	FORMAL INSTRUCTIONS - received by operator - coded only for this type boat No operator..........0 / USCG Auxiliary.......1 / U.S. Power Squadron..2 / American Red Cross...3 / State..........4 / None...........5 / Other..........6 / Unknown........9
MIC	MANUFACTURES CODE - Check boat make and manufacturer hull identification number from manufacturers code book. Code first 3 letters of HIN. Homemade - XXX Unknown - UUU
BOAT TYPE	TYPE OF BOAT Open Motorboat.....1 / Cabin Motorboat....2 / Auxiliary Sail.....3 / Sail Only..........4 / Rowboat............5 / Jet ski............3 / Canoe/Kayak.............6 / Inflatable..............7 / Houseboat...............8 / Other...................0 / Unknown.................9

Figure 4-2 (page 1)

BULL-MAT	BULL MATERIAL	
	Wood...............1 Aluminum...........2 Steel (metal)......3 Fiberglass.........4	Rubber, Vinyl, Canvas...5 Other...................6 Unknown.................9
ENGINE	PROPULSION	
	Outboard...........1 Inboard/Gasoline...2 Inboard, Diesel....3 Inboard/Outboard...4 Jet................5	Sail....................6 Manual..................7 Other...................8 Unknown.................9

HP — HORSEPOWER - Coded directly, horsepower is total of multiple engines.

None - 000   998 or greater - 998   Unknown - 999

LENGTH — LENGTH OF BOAT - Rounded to nearest foot, code directly, if less than 10 prefix "0"

98 ft. or over - 98   Unknown - 99

YR-BUILT — YEAR BOAT BUILT - Last two digits of year built.

Unknown - 99

MONTH — MONTH OF ACCIDENT - (prefix "0" if less than 10)

DAY — DAY OF ACCIDENT - (prefix "0" if less than 10)

YEAR — YEAR OF ACCIDENT - (Code last two digits in year only

TIME — TIME OF ACCIDENT - (Convert to 24 hour clock.

Unknown - 99

TYPWATER — TYPE OF BODY OF WATER

1 OCEANS	2 GREAT LAKES	3 BAYS	4 RIVERS	5 LAKES
Atlantic	Erie	Harbors	Slough	Reservoir
Pacific	Michigan	Island	Creek	Pond
Gulf of Mexico	Huron	Strait	Canal	Dam
Gulf of Maine	Ontario	Channel	Basin	Pit
Lg. Isl Sound	Superior	Delta	Channel	
		Inlets		
		Cove		
		Narrows		
		Sound		
		Intra-coastal Waterway		

Other - 6   Unknown - 9

Figure 4-2 (page 2)

STATE	<u>STATE IN WHICH ACCIDENT OCCURRED</u> - Using standard 2 letter codes. If accident occurred on High Seas outside any state jurisdiction, then accident is coded for state in which boat is numbered or principally used.
COUNTY	<u>COUNTY</u> - Convert a GSA Code Book - <u>NEVER CODE UNKNOWN</u>
WEATHER	<u>WEATHER</u>

Clear..............1	Rain..................4
Cloudy.............2	Snow..................5
Fog................3	Hazy..................6
Unknown............9	

WAT-COND — <u>WATER CONDITIONS</u>

Calm (Waves less than 6")....1	Very rough (Greater than 6')................4
Choppy (Waves 6" - 2 ')......2	Strong Current...........5
Rough (Waves over 2'-6').....3	Unknown..................9

SEA-TEMP — <u>SEA TEMPERATURE</u>

Below 30.............1	70 - 79...............6
30 - 39...............2	80 - 89...............7
40 - 49...............3	90 & Above............8
50 - 59...............4	Unknown...............9
60 - 69...............5	

WIND — <u>WIND</u>

None...................0	Strong..(15-25 MPH)...3
Light..(0-6 MPH).......1	Storm..(Over 25 MPH)..4
Moderate..(7-14 MPH) ..2	Unknown...............9

VIS — <u>VISIBILITY</u>

Good	Fair
Day..................1	Day.................2
Night................4	Night...............5
Poor	
Day..................3	Unknown.............9
Night................6	

Figure 4-2 (page 3)

OPER — OPERATION AT TIME OF ACCIDENT - Code as follows

Cruising	10
Cruising, fishing	11
Cruising, hunting	12
Cruising, sailing	13
Maneuvering	20
Maneuvering, docking	21
Maneuvering, undocking	22
Maneuvering, mooring	23
Maneuvering, towing	24
Water skiing	30
Water skiing, skier down	31
Racing	41
Towing	50
Towing, being towed	51
Drifting	60
Drifting, fishing	61
Drifting, hunting	62
Drifting, diving, swimming	63
Drifting, fueling	64
At anchor	70
At anchor, fishing	71
At anchor, hunting	72
At anchor, diving, swimming	73
At anchor, fueling	74
Tied to dock	80
Tied to dock, fueling	81
Other	98
Unknown	99

ATYPE1 — TYPE OF ACCIDENT - Examine all accident types and choose all which are applicable (if more than 3, choose 3 most important) code in order accident occurred. Example: A collision with a buoy, a passenger falls overboard and was struck by the propeller, would be coded, 09, 10, 12.

Grounding	01	Collision with floating object	09
Capsizing	02	Falls overboard	10
Swamping	03	Falls within boat	11
Sinking	04	Struck by boat or propeller	12
Fire/Explosion (fuel)	05	Fallen Skier	13
Fire/Explosion (other than fuel	06	Other	98
Collision with another vessel	07	Unknown	99
Collision with fixed object	08		

Figure 4-2 (page 4)

PFD

PERSONAL FLOTATION DEVICES - For the operator and up to 3 passengers, code the number which describes the use and type of Personal Flotation Device and whether the boater survived or died.

No PFDs on board - 00
Inadequate number of PFDs on board - 01

Operator Passenger 1 Passenger 2 Passenger 3 Passenger 4

Approved, accessible, used
(By victims)

Type I - 10
Type II - 11
Type III - 12
Type IV - 13
Type V - 14
Type Unknown - 1-

Approved, accessible, used
(By survivors)

Type I - 15
Type II - 16
Type III - 17
Type IV - 18
Type V - 19
Type Unknown - 1+

Approved, accessible, not used
(By victims)

Type I - 20
Type II - 21
Type III - 22
Type IV - 23
Type V - 24
Type Unknown - 2-

Approved, accessible, not used
(By survivors)

Type I - 25
Type II - 26
Type III - 27
Type IV - 28
Type V - 29
Type Unknown - 2+

Approved, not accessible, not used
(By victims)

Type I - 30
Type II - 31
Type III - 32
Type IV - 33
Type V - 34
Type Unknown - 3-

Approved, not accessible, not used
(By survivors)

Type I - 35
Type II - 36
Type III - 37
Type IV - 38
Type V - 39
Type Unknown - 3+

Not approved, accessible, used
(By victims)

Type I - 40
Type II - 41
Type III - 42
Type IV - 43
Type V - 44
Type Unknown - 4-

Not approved, accessible, used
(By survivors)

Type I - 45
Type II - 46
Type III - 47
Type IV - 48
Type V - 49
Type Unknown - 4+

Not approved, accessible, and not used (By victims) - 50
Not approved, accessible, and not used (By survivors) - 55

Not approved, not accessible, and not used (By victims) - 60
Not approved, not accessible, and not used (By survivors) - 65

Other 79
Unknown 99

Figure 4-2 (page 5)

P DAMAGE — PROPERTY DAMAGE - If over $200 round to nearest $100 - in units of $100 - If less than $200 do not code. Code damage to this vessel only.

NDROWN — NUMBER OF DROWNINGS - This vessel only.

NVICTIMS — NUMBER OF OTHER VICTIMS - This vessel only - death other than drownings, do not count those coded as drownings.

NINJURED — NUMBER OF PERSONS INJURED - Persons receiving medical treatment. This vessel only.

NVESSELS — NUMBER OF RECREATIONAL VESSELS INVOLVED - Code recreational vessels only.

CAUSE1 — CAUSE OF ACCIDENT - Select a cause for the accident type coded in type of accident and code in cause. If additional types were coded, select a cause for each accident type if needed. If fewer than three accident types were selected code applicable causes from any cause group.

CAPSIZING - 02, SWAMPING/FLOODING - 03, SINKING - 04

Load related

01 Overloaded
02 Improper weight distribution
03 Standing or sitting on gunnel, bow or transom
04 Movement of passengers
05 Hoisting or lowering anchor

Free water in boat

06 Water entered vessel over transom, gunnel or bow
07 Water entered vessel through hull via drains/vents/hole/crack/etc.

Miscellaneous

08 Force of wake or wave striking vessel
09 Loss of stability during high speed maneuver
10 Loss of stability in strong current, weather, rapids, white water, etc.

FIRE/EXPLOSION (Fuel related - 05, other - 06)

Equipment failure

11 Fuel system (leaking fuel lines, etc.)
12 Electrical system
13 Auxiliary equipment (stoves, heaters, refrigerators, etc.)

Miscellaneous

14 Ignition of spilled fuel or vapor
15 Misuse of source of heat (lanterns, heaters, stoves, etc.)
99 Unknown

FALLS OVERBOARD - 10, FALLS WITHIN BOAT - 11

16	Falls during sharp turns or acceleration
17	Wave or wake striking vessel
18	Falls while moving, standing, or leaning over edge of boat
19	Sitting on gunnel, transom, bow, back of seat, etc.
20	Slippery surface
98	Other
99	Unknown

COLLISION - 07, GROUNDING - 01, STRUCK BY BOAT OR PROPELLER - 12
COLLISION WITH FIXED OBJECT - 08, COLLISION WITH FLOATING OBJECT - 09

Failure to detect hazard

21	Improper lookout
22	Poor visibility (rain, fog, darkness, etc.)
23	View obstructed (bow in air, sun glare, bright lights, etc.)
24	Submerged object (logs, rocks, swimmer, diver, etc.)
25	Operator inattention or carelessness

Miscellaneous

26	Other equipment failure
27	Rules of the Road infraction
28	Speeding
29	Improper navigation lights
30	Starting in gear
31	Navigational error
32	Other vessel/operator at fault
33	Strong current, rough waters, weather, etc.
34	Steering system failure (cable, pulleys, fittings, etc.)
35	Seat breaking loose
36	Overpowered boat
37	Bridge tender error
38	Sail demasting
39	Throttle failure
40	Shift failure
41	Engine failure
42	Inexperience of operator
43	Collision with sailboard
44	Unfamiliarity with waters
98	Other
99	Unknown

Figure 4-2 (page 7)

DESCRIP1
DESCRIP2
DESCRIP3
DESCRIP4

ACCIDENT DESCRIPTORS - Select up to a maximum of three accident descriptors from the following list where needed. Leave unused fields blank.

01 Could not reach fire extinguisher
02 fire extinguisher not serviceable
03 Attempted to fight fire
04 No extinguisher
05 Extinguisher not adequate
06 Put PFD on in water
07 Victim(s) trapped under boat
08 Clung to boat
09 Could not hang on to boat
10 Boat rolling or slippery
11 Could not right boat
12 Left boat/swam for shore
13 Exposure
14 Shock
15 Hypothermia
16 Injured upon entering water
17 Deck fitting failed
18 Exhaustion
19 Lack of swimming ability
20 Runaway boat (engine running without operator)
21 Boat found upright drifting
22 Boat found capsized
23 Ran out of fuel
24 Assisted others
25 Help was nearby
26 Caught in heavy surf
27 Boat went over dam or spillway
28 White water canoeing/rafting/kayaking
29 Boat found, body found, no witnesses
30 Boat hit by lightning
31 Medical complications contributed (heart attack, etc.)
32 Standing in boat starting engine
33 Improperly moored
34 Lack of visual/electronic distress signals contributed
35 Lack of sound producing devices contributed
36 Lack of communications capability contributed
37 Lack of anchor contributed
38 Lack of bailing device contributed
39 Hit and run
40 Wake of other vessel contributed
41 Improper ventilation
42 Failure to vent before starting
43 Improper navigational aid contributed (buoy off station/buoy unlighted)
44 Victim entangled in lines
45 Lines entangled in propeller
46 Operating in congested area
47 Contact with power lines
48 Alcohol involved
49 Drugs involved
50 Coast Guard was directly involved
51 Swimmer or diver involved
52 Inner tubes, kites, etc. involved
53 Water skiing accident
54 Carbon monoxide
55 One or more PFDs not serviceable
56 One or more PFDs not properly used
57 One or more PFDs not properly adjusted
58 One or more PFDs not sized
59 Struck by boat
60 Struck by propeller

61	Unable to determine if struck by boat or propeller
95	Unable to determine if operator contributed to fault
96	Operator contributed to fault
97	Operator did not contribute to fault
98	Collision with commercial vessel
99	Information not available for other boat(s) involved in collision

Figure 4-2 (page 9)

TIMES USING 24 HOUR CLOCK

AM			PM		
12:01	1:30	01	12:01	12:30	12
1:31	2:30	02	12:31	1:30	13
2:31	3:30	03	1:31	2:30	14
3:31	4:30	04	2:31	3:30	15
4:31	5:30	05	3:31	4:30	16
5:31	6:30	06	4:31	5:30	17
6:31	7:30	07	5:31	6:30	18
7:31	8:30	08	6:31	7:30	19
8:31	9:30	09	7:31	8:30	20
9:31	10:30	10	8:31	9:30	21
10:31	11:30	11	9:31	10:30	22
11:31	12:00	12	10:31	11:30	23
			11:31	12:00	24

STATE CODES AND CASE NUMBERS

Alabama	AL	01000-01999
Alaska	AK	02000-02999
Arizona	AZ	03000-03000
Arkansas	AR	04000-04999
California	CA	05000-07999
Colorado	CO	08000-08999
Connecticut	CT	09000-09999
Delaware	DE	10000-10999
Dist. of Col	DC	11000-11999
Florida	FL	12000-13999
Georgia	GA	14000-14999
Hawaii	HI	15000-15999
Idaho	ID	16000-16999
Illinois	IL	17000-17999
Indiana	IN	18000-18999
Iowa	IA	19000-19999
Kansas	KS	20000-20999
Kentucky	KY	21000-21999
Louisiana	LA	22000-22999
Maine	ME	23000-23999
Maryland	MD	24000-25999
Massachusetts	MA	26000-26999
Michigan	MI	27000-28999
Minnesota	MN	29000-29999
Mississippi	MS	30000-30999
Missouri	MO	31000-31999
Montana	MT	32000-32999
Nebraska	NE	33000-33999
Nevada	NV	34000-34999
New Hampshire	NH	35000-35999
New Jersey	NY	36000-37999
New Mexico	NM	38000-38999
New York	NY	39000-40999
North Carolina	NC	41000-41999
North Dakota	ND	42000-42999
Ohio	OH	43000-43999
Oklahoma	OK	44000-44999
Oregon	OR	45000-45999
Pennsylvania	PA	46000-46999
Rhode Island	RI	47000-47999
South Carolina	SC	48000-48999
South Dakota	SD	49000-49999
Tennessee	TN	50000-50999
Texas	TX	51000-52999
Utah	UT	53000-53999
Vermont	VT	54000-54999
Virginia	VA	55000-55999
Washington	WA	56000-57999
West Virginia	WV	58000-58999
Wisconsin	WI	59000-60999
Wyoming	WY	61000-61999
Guam	GU	62000-62999
Puerto Rico	PR	63000-63999
Virgin Island	VI	64000-64999
American Samoa	AQ	65000-65999
Northern Marianas		66000-66999

Figure 4-2 (page 10)

COLLISION ACCIDENT REPORT FORM DATA SHEET

A.Accident ID No.: ____________________
B.Date of Accident: ____________________

1. ACC. Type
   a. CWAV
   b. CWFXO
   c. CWFLO
   d. Grnding

1A. Hit and Run?
   a. Yes ___
   b. No ___

2. Light
   a. daytime
   b. nighttime
   c. dusk
   u. unknown

3. Visibility
   a. good
   b. fair
   c. poor
   u. unknown

VESSEL DESCRIPTION

VESSEL NO 1.(Impacting)	VESSEL NO. 2.(Struck)
4. Length (ft) ________________	8. ____________________
5. Type of Vessel	9. Type of Vessel
a. open motorboat	a.
b. full cabin boat (cruiser, w/steering in cabin)	b.
c. cuddy cabin boat (steering not inside cabin)	c.
d. cabin boat general (b or c, but don't know which)	d.
e. other	e.
6. If 5b, operator was steering from	10.
a. inside the cabin	a.
b. outside the cabin	b.
u. unknown	u.
7. Manufacturer or Model of Boat	11. __________
7A. Manufacturer of engine:	11A. __________
7.1 HP __________	11.1 __________
7.2 Type engine a. OB	11.2 a.
b. I/O	b.
c. I	c.

Figure 4-3 (page 1)

ACCIDENT DATA ON OCCUPANTS

VESSEL NO 1.(Impacting)	VESSEL NO. 2.(Struck)
12. No. occupants ______	17.________________________
13. No. injured ________	18.________________________
14. No. fatalities______	19.________________________
15. Location of occ. inj./killed ______________________	20.________________________ ________________________
15A. No. thrown overboard	20A. ______________________
15B. No. Deaths by drowning that were thrown overboard: _________________________________	20B. ____________________ ____________________
16. Comments on cause of inj./death on occ not thrown overboard: __________________________ __________________________	21.________________________ ________________________ ________________________

CWAV SUBCATEGORIES

22. Collision Basic Situation
a. Both Vessels Moving
b. Vessel No. 1 Moving, Vessel No. 2 Stationary
c. Vessel No. 1 Moving, Vessel no. 2 moving very slowly relative to impacting vessel
u. unknown

23. Estimated Speed of Vessel No. 2 (Struck Vessel), if 22a, or 22c above:
a. Very High Speed, estimated at 40 plus mph
b. High speed, on plane or 20 plus mph
c. Medium Speed, below planing speed, less than 20 mph
d. Low Speed, below hump speed, probably less than 10 mph
u. unknown

24. Estimated Speed of Vessel No. 1, Impacting Boat:
a. Very High Speed, estimated at 40 plus mph
b. High speed, on plane or 20 plus mph
c. Medium Speed, below planing speed, less than 20 mph
d. Low Speed, below hump speed, probably less than 10 mph
u. unknown

Figure 4-3 (page 2)

25. Type of Impact:
    a. Striking Vessel travels over the top of the second
    b. Striking Vesel travels into and/or though the second vessel
    c. Vessel No. 1 makes contact with second, but it is a Glancing Blow or Partial Impact, and does not travel through or over the second.
    d. Combination of one or more of the above, circle as applicable
    u. Totally unknown

26. Initial contact area of impacted boat, Vessel No. 2:
    a. Bow
    b. Stbd Fwd quarter
    c. Stbd side amidships
    d. Stbd rear quarter
    e. Stern
    f. Port rear quarter
    g. Port side amidships
    h. Port fwd quarter

27. Initial contact area of impacting boat or Vessel No. 1:
    a. Bow
    b. Stbd Fwd quarter
    c. Stbd side amidships
    d. Stbd rear quarter
    e. Stern
    f. Port rear quarter
    g. Port side amidships
    h. Port fwd quarter

28. Direction of Impact from Vessel Two's Perspective

29. Relative Size of Vessels:
    a. About the same size
    b. Similar length but different types of boat
    c. One significantly larger than the other

30. Size and Geometry (If 29c above)
    a. Large vessel impacted smaller one
    b. Small vessel impacted the larger onel
    c. Both vessels equally involved in impact
    u. unknown

FOR COLLISIONS WITH FLOATING OR FIXED OBJECT:

31. What was object struck?

32. Estimated speed of vessel prior to impact:
    a. Very High Speed, estimated at 40 plus mph
    b. High speed, on plane or 20 plus mph
    c. Medium Speed, below planing speed, less than 20 mph
    d. Low Speed, below hump speed, probably less than 10 mph
    u. unknown

Figure 4-3 (page 3)

33. Number of occupants:

34. Number of injured:

35. Number of fatalities:

36. Location of occupants:

37. Type of Impact:
   a. direct impact, bow nearly centered, immediate stop
   b. glancing blow
   c. boat ran over top of object
   d. other

38. Describe damage to vessel ______________________________
____
____

39. Did boat swamp, sink or capsize after collision? Which?

40. Comments regarding injuries, occupant locations. What caused innuries/fatalities? Document relationship of injuries to occupants and their locations.

41. Additional Information:
a. weather
b. sea state
c. HP of boat 1 (already covered)
d. alcohol involved?
e. operator standing or sitting?
f. evidence of mechanical failure?
g. operator age, years of experience, training
h. estimates of freeboard at impact points of impacting boat's bow and impacted boat at point of impact
i. Attempts at evasive action?

42. Opinion of officer as to cause:

43. Diagrams or Notes:

Figure 4-3 (page 4)

Summary Of Occupant Data, CWAV

Vessel No. 1

Sum of V1POB:	72
Sum of V1NoInj:	14
Sum of V1NoFatal:	9
Sum of V1NoTOB:	11
Sum of V1Drwnd:	7
Sum of V1NoWOPFD:	5

Vessel No. 2

Sum of V2POB	68
Sum of V2NoInj:	23
Sum of V2NoFatal:	20
Sum of V2NoTOB:	18
Sum of V2Drwnd:	6
Sum of V2NoWOPFD:	3

KEY:

V1	=	Vessel No. 1
V2	=	Vessel No. 2
POB	=	Persons on Board
No Inj.	=	No. Injured
No Fatal	=	No. Fatally Injured
NoTOB	=	No. Thrown Overboard
Drwnd	=	No. Drowned
NoWOPFD	=	No. Who Were Not Wearing PFD

Figure 4-4

Collisions With Fixed Object
Summary Data

Sum of V1POB:	66
Sum of V1NoInj:	17
Sum of V1NoFatal:	23
Sum of V1NoTOB:	40
Sum of V1Drwnd:	12
Sum of V1NoWOPFD:	5

KEY:

V1	=	Vessel No. 1
V2	=	Vessel No. 2
POB	=	Persons on Board
No Inj.	=	No. Injured
No Fatal	=	No. Fatally Injured
NoTOB	=	No. Thrown Overboard
Drwnd	=	No. Drowned
NoWOPFD	=	No. Who Were Not Wearing PFD

Figure 4-5

Collisions With Floating Object (CWFLO) Summary Report

Sum of V1POB:	20
Sum of V1NoInj:	3
Sum of V1NoFatal:	8
Sum of V1NoTOB:	15
Sum of V1Drwnd:	6
Sum of V1NoWOPFD:	0

<u>KEY</u>:

V1	=	Vessel No. 1
V2	=	Vessel No. 2
POB	=	Persons on Board
No Inj.	=	No. Injured
No Fatal	=	No. Fatally Injured
NoTOB	=	No. Thrown Overboard
Drwnd	=	No. Drowned
NoWOPFD	=	No. Who Were Not Wearing PFD

Figure 4-6

CHAPTER 5

THE DIFFERENCE IN ENVIRONMENTS
Between the Boat and Auto

5.0 Introduction

Boat collisions are vastly different from automobile collisions for a variety of reasons. Obviously, there are differences between boats and cars, but there are also dramatic differences in the environment in which each operates. The purposes of this chapter are to examine the ways in which the boating environment differs from that of the automobile, and to understand how these differences affect collision accidents.

5.1 The Environment- Stop Signs, Yellow Lines, and Channel Markers?

The most obvious difference between auto and boat collisions is the environment in which they occur. Automobiles are blessed with good roads, well marked traffic control devices, and clear enforceable traffic laws.

Boats have the freedom to travel in any direction. The laws governing right of way vary from one state to another. We even encountered one state that had not incorporated any specific rules of the road into their boating laws. There are no waterborne equivalents to stop lights, yield signs or other similar devices. Boaters frequently have channel markers and no wake zones to abide by, but only limited devices (buoys) to control traffic flow at aquatic intersections.

One obvious advantage of the closely controlled environment of the automobile is that an accident investigator generally knows which direction each vehicle was traveling. There is not much in question about which street the car was on, or whether it came from the left or the right. The boating accident investigator, however can make no assumptions about speed or direction of travel based on the accident site.

5.2 The Operator - Dad, Can I Drive?
Operator Experience and Capability

Operators of varying ages, experience levels, health conditions, and capabilities may be found operating either a boat or an automobile. While there are variations in both environments, far fewer assumptions can be made about the operator of a boat. The operator of an automobile is generally at least 16 years of age and has an operator's license. Today, most youth go through a

driver's education class, drive with a permit for a time which requires that an experienced operator be present, and finally go to apply for their driver's license. To obtain the license, a written test, an eye exam, and a road test with an examiner present is required. The government has put a mechanism in place to ensure that people: 1) are familiar with the laws; 2) can physically see well enough to perform the tasks of an operator; and 3) perform basic vehicle operations in a safe manner with an examiner present. Anyone reading this report is most likely familiar with this process. It is worth repeating because of the stark contrast to the requirements for operating a boat.

As a general rule, the operator of a recreational boat may be any age, in any physical condition, and at any experience level. In most cases, there is no training or licensing required to operate any recreational boat, regardless of its size, horsepower, or potential speed. As of this writing, certain states are considering legislation which would require minimum age limits, licensing, and other measures to provide some level of operator proficiency, but few states have actually adopted such requirements.

5.3 The Question of Alcohol

An important distinction to make between recreational boats and automobiles is that in boats the emphasis is placed on the word "recreational." Thus, the careful automobile driver who would never think of drinking and driving, picks up a few cases of his favorite beverage on the way to the lake. The bottom line is that alcohol may be even more of a problem on the water than on the highway in terms of the percentage of accidents in which alcohol was a contributing factor. The law enforcement community as a whole has stepped up efforts to adopt and enforce some version of a boating under the influence (BUI) law, or a boating while intoxicated (BWI) law. Many experts give credit for reduced fatality rates in recent years to the law enforcement community and increased efforts in boater education.

5.4 The Vehicle

The differences between boats and cars go far beyond the obvious. We all know that boats do not have wheels, and cars do not float, at least not for long. The important differences lie in the operator's environment. Many of these differences were clearly pointed out in Boating Safety Circular no. 72 published by the USCG Recreational Boating Products Assurance Branch. This topic could be the subject of a research project by itself, so we will only highlight a few important differences.

5.4.1 All Sizes and Shapes

Automobiles are generally thought of as coming in all shapes and sizes. Compared to boats, this is not really the case. In fact, most cars are less than 20 feet long, 8 feet wide, and under 5,000 pounds. An average car cruises comfortably at 65 mph and has a top speed ranging from 90 to 120 mph. Cars also have four wheels, an energy absorbing suspension system, and brakes for stopping.

Recreational boats range anywhere from small dinghies eight feet in length to large luxurious yachts over 100 feet long. A dinghy may weigh under 100 pounds, and large boats displace many tons. The typical boater has a boat from 16 to 26 feet in length, with a top speed of 35 to 45 mph. America has recently witnessed an obsession with speed as an increasing number of boats travel up to 100 mph right from the dealership. Boats have differing fundamental hull shapes, such a the V-hull, tri-hull, pontoon boats, flat bottom, and round bottom, to name a few. Each hull type reacts differently in an accident.

The competent automobile driver can generally go from one vehicle to another and operate it under normal conditions with the same degree of skill and efficiency. On the other hand, the operator of a 16 foot ski boat may purchase a 35 foot cruiser and find himself suddenly inadequate at even the most basic maneuvers, such as docking. The wide variety of boat types, lengths, and performance characteristics means that the possible combinations of boats involved in a collision are greater than for automobiles. If an automobile accident investigator takes into account that cars can run into tractor trailers, freight trains, and an occasional bulldozer or crane, then perhaps the numbers of possible combinations are a little closer to that of the boating environment.

5.4.2 Operator's Environment

The differences between the boat and the automobile can be divided into two areas: the operator's environment, and the crashworthiness of the vehicle. The first area includes all the tools necessary for the operator to operate his vehicle safely, thus minimizing the chances of a collision occurring. The second includes how well the operator (and passengers) are protected in the event that an accident does occur.

5.4.3 Operator Controls and Visibility

The operator of an automobile sits in a comfortable padded seat with a sturdy frame designed to remain attached to the floorpan during an accident. The controls are well placed so that he does not have to leave his driver's position to operate them. The windshield, side, and rear glass offer good visibility and

minimum glare. Windshield wipers are concealed from the driver's view until needed. Defrosters can remove fog from the windshield in a few moments. Rear window wipers and side window defoggers are now becoming more common. The operator and passengers are protected by padded surfaces, collapsible steering wheels, three point seat belts, and often, air bags.

The boat operator has quite a different situation. When the operator sits down in the seat of many 16 to 26 foot motorboats, the windshield frame may is at eye level or slightly above. Immediately, he must contend with the frame blocking part of his vision. If the boat is a bow-rider, he may also permit passengers forward, which may further obstruct his vision. It must be remembered that planing boats go through a period where the bow rises while the boat gets up on plane. Forward vision during this transition period may be completely obstructed. To help contend with this situation, the operator will sit on his seat back in order to see where he is going. When he does so, the controls, including the throttle, are not within easy reach. This can be especially dangerous since the throttle will stay in the position in which it was placed. This is unlike an automobile which requires constant pedal pressure to keep the throttle engaged, except when the cruise control is engaged. If the operator falls out of the boat, the throttle will remain engaged as the boat travels on, unattended. Windshield wipers are seldom present on small boats. When they are provided, the windshield wipers and motors themselves may obscure part of the driver's vision, since they are often mounted on the top part of the windshield. When operating, they usually only clear a relatively small part of the windshield.

5.4.4 Operator and Passenger Protection

The operator of today's automobile is traveling in a product developed from more than 80 years of research, at a cost of billions of dollars. Everything from the bumpers to the steering wheel is designed with occupant protection in mind. Safety glass is used throughout. The dash and surrounding surfaces are padded. The seats and seat belts meet strict structural requirements. Air bags and three point seat belts provide increased levels of protection over early production automobiles.

In contrast, the operator of a small powerboat sits in a seat, with no federal minimum requirements for structural integrity, which may break loose during an impact. The windshield frame is often constructed from thin aluminum with the top of the frame right at eye level. Windshields with a center opening section frequently have sharp corners where passengers walk through. There are no requirements to minimize glare, so bright, shiny handrails may reflect sunlight back into the operator's eyes. Many boat manufacturers today are using safety glass; however, there are still no federal requirements for it.

The boater starts off with a slight disadvantage in equipment when compared to the automobile. The differences are often subtle and may not reveal their adverse affects except in bad weather, at night, or on crowded waterways. Problems with the operator's poor environment are revealed when an accident occurs that could have been avoided and injuries which should have been minor resulted in a fatality.

5.5 Collision Differences at Night

Collisions at night are common for both cars and boats, but not necessarily for the same reasons. Collisions between automobiles may occur at night because one driver failed to see another vehicle; however, they often occur for the same reasons that they do during the day. Collisions between boats at night, on the other hand, are almost always because one operator failed to see the other vessel in time.

The lighting system on boats is dramatically different from that of their four wheeled counterparts. The lights on recreational boats are often difficult to see. They may blend in with background lighting so well that they are unrecognizable. Boats are not equipped with headlights like automobiles. Headlights provide automobile operators with a means to see where they are going. They also provide a great method of spotting other vehicles, even while they are a great distance away. Small boats at anchor may only have a single white light at the stern of the boat. This single light can be especially difficult to detect at night, when background lighting on a shore is present.

It is not uncommon for a boat operator to literally drive over an anchored boat at night, and report that he never saw it. This type of occurrence has been documented with alert, fully sober operators. The obvious question in these cases is "Did the anchored boat have lights on?" Many night time collisions occur even when both boats' lights are operating properly. The point to be made is that the lighting system on boats does not afford the same kind of visibility as those on automobiles. To avoid an accident, an operator must still maintain a sharp lookout, and keep speeds down to a reasonable level when traveling at night.

It has been documented that many navigation lights currently installed on recreational boats do not meet the minimum visibility requirements required by USCG regulations. As a result, it is difficult to determine the adequacy of the current navigation light requirements since it is unknown how many boats have lights which actually comply with the regulations. A first step toward addressing the problem of collisions at night may be for the USCG to take stronger measures to ensure that navigation lights installed on today's recreational boats meet the minimum requirements.

5.6 Effects of the Environment on the Operator

Much research has been conducted to determine how various environmental factors affect the human body. Sun, wind, vibration, and noise are all factors that may be present in either boats or cars. There is little question that the boater's environment is generally more severe than that of the automobile operator.

An automobile is equipped with a suspension system that minimizes the shock of bumps and the vibration of the roadway. Even the seat has its own built-in isolation system to provide comfort to the driver. Autos (except convertibles) have enclosed passenger compartments, which protect the occupants from direct exposure to the elements, such as sun and wind.

In contrast, the boater may spend all day in an open motorboat, directly subjected to the sun and wind. Vibration and shock levels when cruising, especially on rough water, can fatigue an operator rather quickly. Fatigue, decreased reaction times, and impaired judgement are but a few ways that the boat operator is affected by his environment. When these effects are combined with alcohol, a potentially fatal combination results.

5.7 Summary

The purpose of this chapter is not to criticize boats or boat manufacturers for their differences when compared to automobiles. It is simply to point out some of the ways that the environment of the boat operator differs from that of the automobile driver. The understanding of these differences and their implications is essential to the understanding of boating accidents.

The reconstruction of recreational boat collisions is a task that many skeptics consider impossible. Many skeptics respond "There are simply too many variables and there are no skidmarks on the water." Yet many boat collisions can be reconstructed if the reconstructionist understands boats and the marine environment.

Hopefully, this chapter provides an enlightening comparison between automobile and boat collisions. The comparison is useful because automobile collisions are a topic that is familiar to most. It lets us start on familiar ground. It is also useful because it allows us the opportunity to point out some dramatic differences between the two that are not so obvious.

CHAPTER 6

COMPARISON OF BOAT AND AUTO COLLISIONS
Skidmarks on the Water

6.0 Introduction

The reconstruction of recreational boat collisions is a task that many skeptics consider impossible. Many skeptics have commented that "There are simply too many variables and no skidmarks on the water." The purpose of this chapter is to provide an enlightening comparison between automobile collisions and boat collisions. The comparison is useful because automobile collisions are a topic that is familiar to most. This approach will let us start on familiar ground and then let us gradually get our feet wet as we explore boat collisions. We will be able to point out important differences between the two that may not be obvious. Our goal in this chapter is to provide a brief overview of some of the significant differences. Some of these differences will be explored in more detail later.

6.1 The Automobile Reconstructionist and the Flat World

The automobile reconstructionist lives in a flat world. Most automobile accidents are fundamentally treated as two-dimensional collisions. When was the last time you heard of an automobile accident where one car literally ran over the top of another one? Probably never, right? While it may happen on occasion, such events are definitely the exception rather than the rule. Technically, any automobile collision involves all three dimensions, however two-dimensional approximations serve accurately enough for most reconstructions.

What we really mean by two dimensional collisions is that the collision process can be considered to have occurred in a plane. As long as both cars remain in contact with the ground, two dimensional approximations are well suited for an analysis. Some of the most popular automobile accident reconstruction computer programs are only capable of performing a two-dimensional analysis. This greatly simplifies the conservation of momentum equations often used to estimate speed. We will study more about this technique later, but for now it is enough to remember that the ability to practically consider an automobile collision as a two-dimensional event greatly simplifies the analysis.

In a typical automobile accident, two cars collide with each other, deform, and then continue on a path consistent with the laws of the conservation of momentum. The collision is normally considered to have occur in the horizontal plane. Such is not the case with a typical boat collision!

6.2 The Two Boat Collision - Watch Your Altitude!

The officer watched intensely as a 19 foot center console, open fishing boat sped toward a motionless 17 foot tri-hull. The fishing boat was traveling about 30 mph. With a loud crack and a sickening crunch, the 19 foot fishing boat drove through and over the tri-hull, striking at a 90 degree angle, approximately 1/3 of a boat length from the stern. The bow of the fishing boat pitched sharply upward, and the fishing boat took off through the air like it had driven over a giant floating ramp. It splashed down about 40 ft from the impact point, leaving the tri-hull in a serious state of disrepair. The 19 foot fishing boat kept its speed, drove up on shore, and disappeared behind the trees near the shoreline. The officer cheered, laughed, and stared in utter amazement at what he had seen, along with about a hundred of his fellow law enforcement officers. This was not an accident. It was a staged collision! This was an experiment performed as part of a seminar on boating accident investigation conducted by UL for the Florida Marine Patrol in 1988. For many officers and engineers it was an historic event because it marked the first time that many of these men and women ever saw an actual collision occur. In an instant, many of the theories they had formulated over the years about what happens in a boating accident went right out the window. You're right -- it is nothing at all like a car accident!

Not all boat collisions are similar. They come in as many varieties as automobile collisions, but that is where the similarity ends. It is important to remember that when two boats collide, the resulting dynamics most likely will involve three dimensions, with the third dimension being vertical. While not all collisions result in a boat flying through the air over a great distance, even glancing blows and low speed impacts may result in one or both boats being displaced significantly in the vertical direction. This is one of the reasons that occupants in a boat collision may be ejected from the boat, especially from the striking boat.

One of the most common boating collision scenarios is some form of an over-ride, when one boat literally runs over the top of another boat. The curved bow of the average powerboat is a strong structure that is ideal for riding over things. After all, that is precisely what it is designed to do. The bow of a boat is designed to ride over waves, and rough water. It also does a great job of helping the boat ride over other objects, such as other vessels. Often when this occurs, the striking boat, sometimes called the bullet boat, suffers relatively little damage. The occupants in the striking boat frequently suffer little or no injuries. The struck boat, sometimes referred to as the target boat, generally suffers heavy damage and its occupants are at greater risk of severe injury or even death than the occupants of the striking boat. In an over-ride type accident, it is generally true that the occupants of the boat on the bottom are in much greater danger than their counterparts on top. Generally this is true, regardless of the structure or type of boat that ends up on the bottom.

It would be very unusual indeed for two small boats to hit each other, deform, and bounce off, remaining completely in a horizontal plane. That is a general description of an automobile accident. Cars tend to run into each other, boats tend to travel through and/or over one another. In an auto accident, the damage to each depends largely on the relative strength of each automobile. In boat collisions, the boat on the bottom is almost always more severely damaged than the one on top.

6.3 Differences in Structures and Materials -

Another obvious difference between cars and boats is the materials used in their construction. Once again, these differences are important for many not so obvious reasons. Remembering that our primary focus is on collisions and collision accident reconstruction, we will look in detail at the following concepts:

1. Fiberglass reacts differently under impact than metal.

2. A boat will not deform in the same manner as an automobile during an accident.

3. Differences in individual construction techniques for similar types and classes of boats may have little effect on the results of a collision.

6.4 Reactions of Fiberglass and Metal in a Collision

6.4.1 Metals - They Bend, But They Won't Break!

If you have ever been to the junkyard, you have probably seen the car that ran head-on into a telephone pole. It is badly deformed, yet you can easily tell that this vehicle ran into a stiff, cylindrical structure. Chances are pretty good that you could even tell the diameter of the pole by measuring the damaged area on the car. The reason you can do this is because the metal from which the car is made had deformed, conforming its shape to match the struck object. The metal actually deformed slightly beyond what is visible after an accident; however, the residual crush shape is generally close in appearance to its maximum deformation.

The metal body and frame in an automobile will usually retain a shape close to that which occurred at maximum deformation. It will have a tendency to spring back slightly, but it is usually not a significant amount. This characteristic provides the accident investigator with a wealth of information about the details of the actual collision. It is not unusual for imprints of key parts such as a headlight frame or a door handle from the other vehicle to be found in the dented metal body panels of a vehicle. This kind of information is useful for determining relative locations of each vehicle as an impact occurred and progressed.

The metals used in an automobile involved in a collision leave a record of dents, twists, bends, and other deformations which provide data that can be critical in reconstructing an accident. Although it can be difficult to ascertain how each deformation occurred, this information is often essential in order to reconstruct the accident.

6.4.2 Fiberglass - It Bends and It Breaks, but It Won't Stay Put!

Examining a fiberglass boat after a collision can be a very frustrating experience. The boat may have random damage patterns that appear to be more the result of vandals with sledge hammers than a collision with another boat. Areas where heavy damage would be expected might look barely touched, while other areas may seem totally devastated for no apparent reason.

Part of the explanation for these damage patterns is due to the nature of the fiberglass material. Fiberglass has an amazing ability to deform during impact and return to something close to its original orientation. For example, in a T-bone collision, such as the staged accident described in the previous section, the 19 foot fishing boat traveled through one side of the tri-hull. What kind of damage would you expect to see on the tri-hull? If the material was perfectly brittle, you may expect to see a cut-out in the side of the hull the same shape as the hull which penetrated it, just like a boat shaped cookie cutter. Unfortunately, the damage in fiberglass often does not resemble the shape of the object which penetrated it, at least not until you know what you are looking for! For our T-bone collision, a simplified damage diagram is shown in Figure 6-1. Here, the fiberglass is fractured completely through along line 1. Two angular cracks along lines 2 and 3 form and act as hinges, allowing the panels noted by 4 and 5 to fold out of the way. After the accident, the panels may actually snap back into position, making it look almost as though nothing major happened. The brittle fiberglass resin and external gelcoat is fractured; however, much of the actual glass cloth and mat still holds the panels in place. The glass cloth and math acts as a spring attempting to hold everything in its original position.

The point of the previous discussion is to illustrate how boat materials differ from automobile materials in a collision. The analysis of fiberglass damage on a boat may be more complex than analyzing damage to automobiles. Fiberglass does not leave behind as clear a record of what happened as the metal on cars. What is left behind can be difficult to interpret. All fiberglass is not created equal. It is possible that varying construction practices including laying up fiberglass and the placement of structural members in a hull may affect how the hull material responds in a collision, further complicating the analysis. We will discuss more details on fiberglass examination in a later chapter.

6.5 Vehicle Deformation Characteristics

While we are contrasting automobile and boat collisions, it is worthwhile to note differences in how each tend to behave in a severe impact. A good example is to revisit the car which struck the telephone pole in section 2.1.

Let's assume that the car struck the pole head on, but off center so that the pole struck the car two feet to the right of the car's centerline. The crushed car may resemble the one shown in figure 6-2a. The pole only contacted a small portion of the front end of the vehicle, yet the entire front of the car is deformed as a result of the impact.

Now consider the same scenario with a boat. A collision of a 23 foot cruiser with a steel I-beam which supported a channel marker is an analogous situation. Figure 6-2b shows an outline of the damage to the cruiser after the impact. The channel marker penetrated deep into the structure of the cruiser, cutting both the foredeck and the bottom of the hull, as well as everything in between.

Consider one further example, which involves a T-bone impact with two automobiles. Figure 6-3a shows the outline of the damage to a vehicle in a high speed accident. The entire vehicle is actually bent into a "V" shape.

The similar scenario for boats could fall into one of two situations. In both examples, we will assume the struck boat has a velocity of zero. Figure 6-3b shows what the result might be in the event that an over-ride occurred during the collision. Here, the initially struck side of the boat is damaged but the other side is virtually untouched. An over-ride situation is not always the result of such an accident. It is possible to end up with the results shown in Figure 6-3c where total penetration has occurred. This is more likely in a scenario where a small boat traveling at high speed strikes a large boat with high sides. In both cases, the damage to the striking boat is probably slight compared to the struck boat.

These examples illustrate better than words how differently the deformations between a boat and a car can be in seemingly similar situations. In general, automobiles tend to show damage over an area much wider than just the area affected by contact damage. This is because of induced damage. Induced damage is damage to a vehicle which occurs by other than contact damage.

Much of the damaged area on a boat is from contact damage. Boats do show induced damage, but it may not be as widespread as on automobiles and it takes on a much different form. Induced damage on a boat may appear as stress cracks in fiberglass some distance away from an impact point. It may also be seen as the displacement and separation of some portion of the deck cap from the hull in an area well away from the impact point.

Boats react differently from automobiles in a collision for many reasons, not just because of the difference in materials. One reason is simply because of the dramatic difference in shape of the outer structure. When automobiles collide with each other, a relatively blunt surface, usually the front of a vehicle, is coming into contact with the second vehicle. This blunt impact tends to cause the loads on both vehicles to be distributed over a wide area, keeping local stresses relatively low compared to an impact with a pointed object. The resulting impact usually causes deformations rather than penetration of the material. The strong metals, such as the steels found in automobiles, resists penetration better than fiberglass.

Let's look in more detail at a typical T-bone impact between two boats. First, the pointed bow on the bullet boat with a small contact area strikes the hull of the target boat. Penetration occurs almost immediately. As the collision progresses, the hole punched by the bow is widened as the wider portions of the striking boat's hull pass through the target boat's hull. The effect is somewhat like a wedge. The event happens quickly, and large sections of fiberglass may just fold back out of the way. These sections may spring back in place after the collision, or may be removed entirely, depending upon the brittleness of the material. Depending upon the hull geometry, boat structure, and initial relative contact positions of both boats, the bullet boat will either over-ride or penetrate the target vessel. This description explains that boats interact very differently during a collision than do automobiles.

6.6 Differences in the Data Available for Boat and Automobile Collisions

6.6.1 Scene Data

Gathering data at the scene of an automobile collision is a crucial step in the development of a collision reconstruction. Key information obtained at the scene of an automobile accident includes:

a. Final rest position of the vehicles
b. Impact point on the roadway
c. Documentation of all skidmarks, scrapes, and evidence of vehicle contact with the roadway
d. All vehicle debris on the roadway showing location and types of debris.
e. Data for the measurement or estimation of drag factors such as type of road surface, general condition of road surface, was surface wet or dry, etc.
f. The layout of roadways and intersections
g. General layout of the area, including radius of curves, slopes of hills, sight distances from various points on the roadway

h. Notation of sources of light depending on time of accident, which could include the sun, street lights, store lights, lighted signs, and other light sources that affect visibility

The list above is certainly not complete, but it does provide a good idea of just how much data an automobile accident reconstructionist may have available from the accident scene. In many automobile accidents, the investigating officer is able to arrive on the scene before any of the vehicles are moved and he has the opportunity to document untainted data. Reality and practical experience have shown that all of this data may not be available to the investigator, depending upon when he learns of the accident. The point is, in many auto accidents, all of the above information could be obtained.

Now consider the situation of the boating accident investigator. Even in the best possible situations, there are no indications of a final rest position of the vehicles, impact points on the waterway, or clearly defined debris fields. The investigator is not usually blessed with the knowledge of the precise area in which a collision occurred. The obvious exception is when a collision occurs with a fixed object, such as a tree or bridge piling. Witnesses may point to a general area where an accident took place, however exact locations are often difficult to pinpoint. This can make a driver view field analysis difficult if other objects such as islands, trees or other obstructions possibly played a role in preventing one boat from seeing the other.

The boating accident investigator is fortunate if in a two boat collision, both boats are actually available. Often one sinks or the operator of one vessel will flee the scene. Some states do not have laws that permit the seizure of vessels after an accident. Consequently, any data which could have been obtained by a detailed examination of the vessel has been forfeited.

A common problem for the boating accident investigator is that it may be hours, days, or in rare cases, more than a week before he learns of an accident. Since the USCG estimates that only about ten percent of the accidents are reported at all, it is easy to see that many boat operators may not feel compelled to report an accident immediately afterward. If the investigator does not receive a report for several days after the accident, the risk of contamination of the data is high. This is especially true for items such as switch positions, throttle positions, and faulty equipment which may be easily altered. This further complicates any attempts at conducting an accurate reconstruction of the accident.

Obviously, there are certain pieces of information which cannot be retrieved from the scene of a boating accident. Even so, much can be done with regard to gathering scene data from a boating collision. The data is not likely to be as significant or as detailed as that for an automobile accident; however, it can prove to be useful. We will cover the details of scene documentation in a later chapter.

6.6.2 Vehicle Data

The accident reconstructionist generally needs to know basic information about the vehicles involved in an accident, whether they are boats or cars. Volumes of data are generally available on automobiles that provide weights, CG locations, wheelbase, track, and overall dimensions as well as a variety of other technical specifications.

The automobile industry is required to show that passenger cars meet federal motor vehicle safety standards for a variety of areas including crashworthiness and occupant protection. As a result, a tremendous database of information has been compiled on crush data for front end and rear end impacts. The amount of data collected has been sufficient to develop generic formulas that show the relationship of crush distance to energy, and, therefore, impact speed. Even if crash data is not available on a specific model automobile, approximations may be used instead, which are based on the generic coefficients for a particular size of vehicle. Many automobile accident computer simulation programs provide the option of using known crush coefficients for a particular vehicle or the alternate values may be calculated based on generic information about the vehicle. Since crush coefficients may vary within a particular class of vehicle, the accuracy of the generic coefficients is somewhat open to discussion.

It is important to realize that the same kinds of generalized data are not available for boats. Any critical information about a boat may have to be obtained by measurement or by calculations. A manufacturer's sales brochure may contain certain basic specifications for its series of boats, but the accuracy of those values is unknown and depends upon the options installed. It is easy to measure a boat to obtain the overall length, maximum beam, and the weight. Unfortunately, that is probably the only way, in many cases, to obtain that data! It is another matter entirely to obtain more complex data such as CG height or moments of inertia. It is possible to write the manufacturer and request the desired information, but the company may refuse to release the desired information or be out of business.

There is no boating equivalent to automobile crush data, and even if it were available, it would not likely have the same value. Unfortunately, there is not any widely published data on strengths, types of construction, or other structural properties of particular types of recreational boats. Textbooks on fiberglass, composite materials, boat building, and related subjects may publish data on fiberglass material properties. The properties of the fiberglass on any given boat may differ substantially from published figures in a textbook. Even if the structural data were available for a particular boat, it would take extensive testing to apply meaning to that data as it relates to boat hull structural deformations in various impact situations. Experimental collisions have demonstrated that, for certain types of impacts, the precise characteristics of the boat structure may be almost irrelevant to

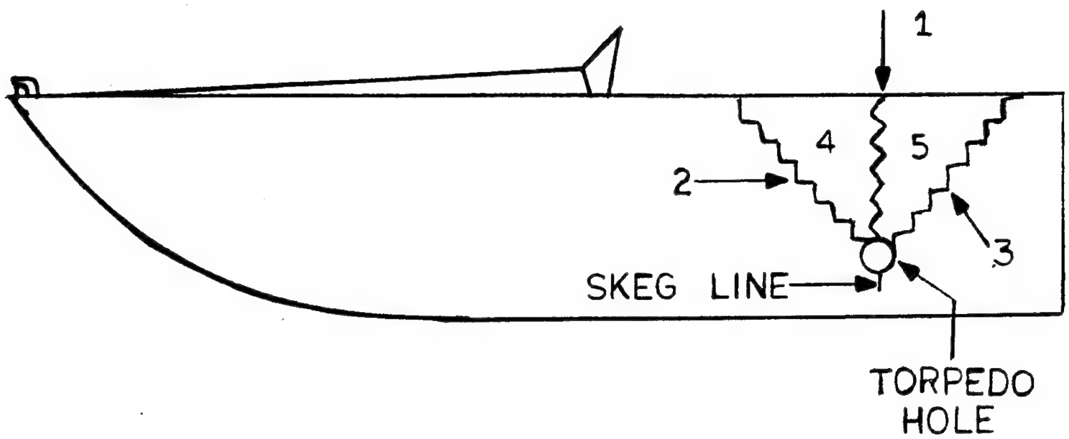
the outcome. This is especially true for side impacts, where only the boat hull side is penetrated by a bullet boat. Above a speed of roughly 20 mph, most common hull side constructions may be relatively easily penetrated by most bullet boats.

Today, we know much about how an automobile responds during a collision. We know how an automobile deforms, how much energy is required for certain deformations, how the occupants react, what forces act on the occupants, and we have reams of data available on the vehicle and its structure.

On the other hand, we know comparatively little today about the way boats respond in a collision. Much is yet to be learned about how boats deform and react in an impact. As of this writing, we are not aware of any experimental collisions which have been conducted in a scientific manner using instrumented boats. This kind of data can be expensive to obtain, and requires modern data acquisition systems and instrumentation. It is the kind of testing that needs to be done to document the forces and accelerations on each boat and its occupants in real collision scenarios.

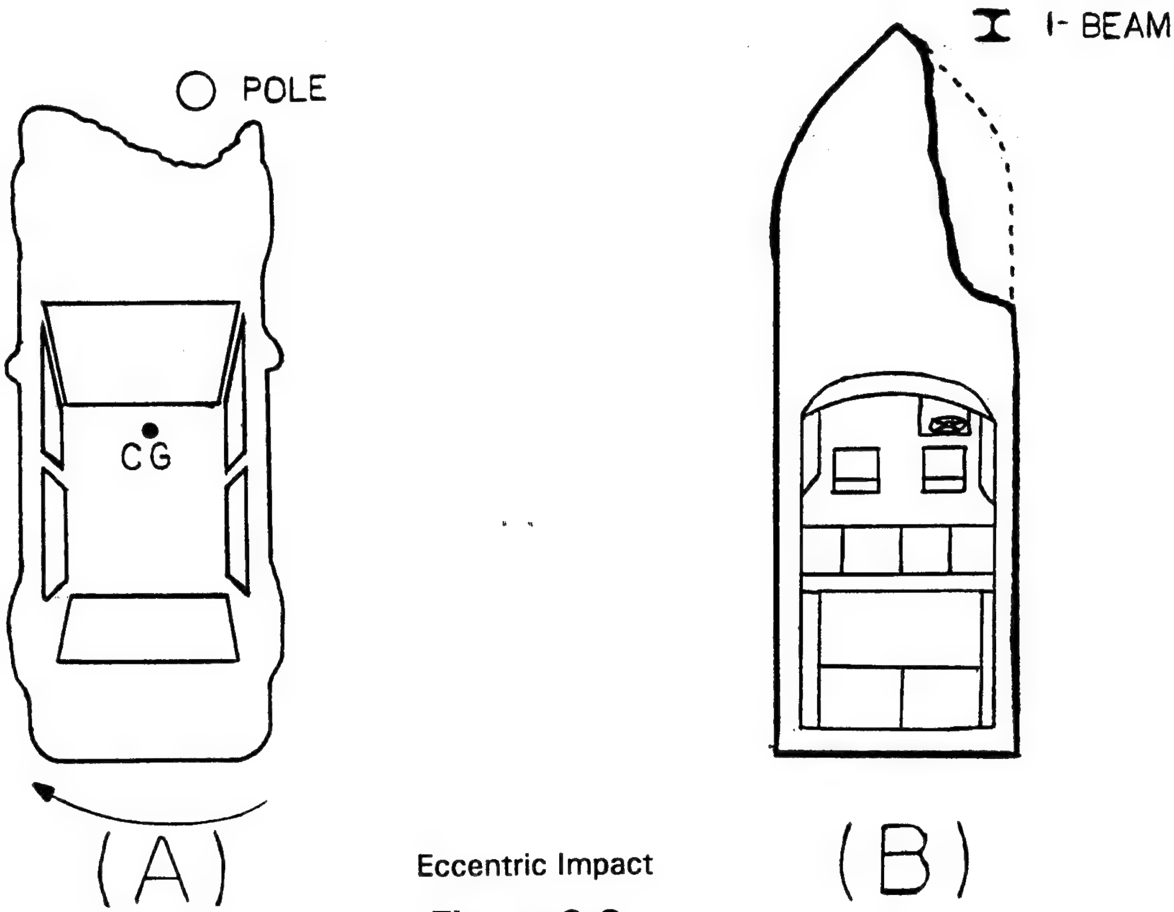
The scientific reconstruction of boating collision accidents is a new field. When a serious boating accident occurs and an experienced accident reconstructionist is needed, it is usually obvious fairly soon that there are virtually no boating accident reconstruction experts to be found. Speculators and guessers abound, but few people have really tried to apply in depth scientific and engineering principles to boating accident reconstruction. The temptation then is to get the automobile reconstruction expert in the area to reconstruct the boat accident. After all, a collision is a collision, right? Wrong! For most situations, they are not even close!

It is important when conducting boat accident reconstructions to consider the differences between automobile collisions and boat collisions. The investigator must not be took quick to apply concepts of automobile accident reconstruction to boating accidents.



Typical Damage to Hull Side After Collision

Figure 6-1



Eccentric Impact

Figure 6-2

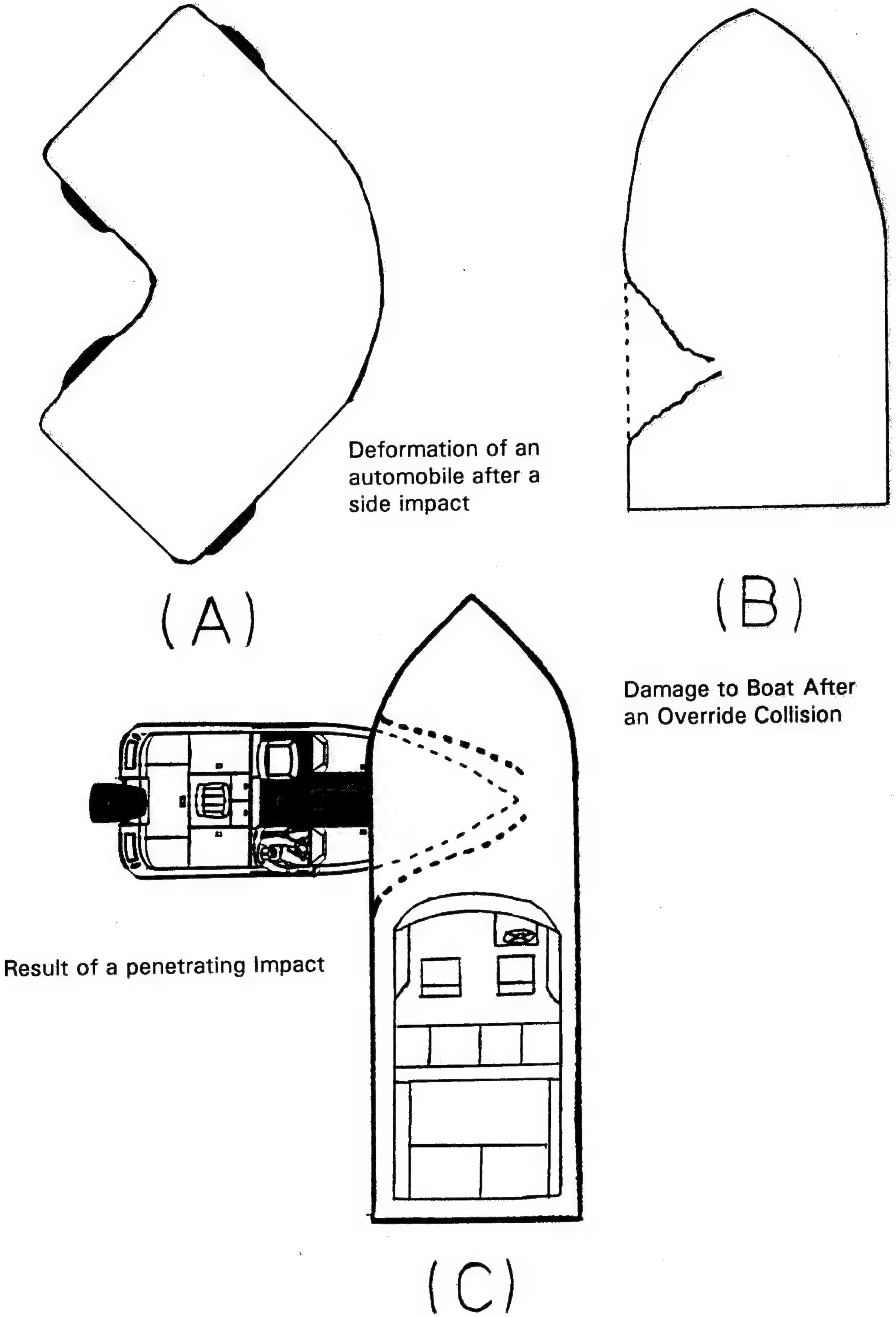

Deformation of an automobile after a side impact
(A)
(B)
Damage to Boat After an Override Collision
Result of a penetrating Impact
(C)

Figure 6-3

CHAPTER 7

FUNDAMENTAL PRINCIPLES OF COLLISIONS

7.0 Introduction

The complexity of any subject is dependent upon how much detail one needs to know. Even the space shuttle can be explained in simple terms if one does not require much detail. To the child, it is just a special type of airplane that carries men and science experiments into orbit. The space shuttle engineers would not likely be pleased with such an explanation! The space shuttle is one of the most complex, and advanced engineering feats ever accomplished. The task of analyzing boat collisions is also a subject that may appear fairly simple, yet is truly a complex subject. On the surface it appears to be a rather simple subject.

In this chapter, we will conduct a review of some of the fundamental physical concepts as they apply to boats and small boat collisions. The practical application of many of these concepts will be illustrated by example throughout this chapter. Our efforts will be concentrated upon explaining how each of these factors relate to the problem of understanding boat collisions.

7.1 Fundamental Physical Principles

We could start from the beginning with explanations of mass, weight, gravity, and numerous other concepts of physics crucial to our understanding of collisions. Numerous textbooks are available on basic physics, and it is beyond the scope of this report to provide a tutorial in basic physics. We will provide a summary of some of the basics with which the reader needs to be familiar. Some of the key concepts surrounding boat collision analysis are:

1. Weight, mass, and center of gravity.
2. Buoyancy, center of buoyancy, and buoyant forces.
3. Inertia, mass moments of inertia, polar moments of inertia
4. Newton's laws of motion, which for reference are summarized below:

    a. Newton's First Law: Every body persists in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces impressed on it. In other words, a body at rest tends to stay at rest, and a body in motion tends to stay in motion.

b. Newton's Second Law: An object of a given mass m, will accelerate at a rate proportional to the net force exerted, and is best expressed by the mathematical relationship of Force = mass times acceleration, or more simply $F = ma$.

c. Newton's Third Law: For every action there is always an equal and opposite reaction.

5. Friction- both static and dynamic.
6. Basics of structures and basic terms of structural mechanics.
7. Principles of rotating bodies about a fixed axis, specifically the relationship of $T = I \times (a_r)$ where T = Torque, I = the moment of inertia, and a_r = acceleration, rotational.

If at this point you are not familiar with all of the concepts above, it is not necessary to panic or to return to college and plead with a physics professor. Most of the terms and concepts will be used and explained in the context of this report in such a way as to provide at least basic understanding.

7.2 Basics About Boats

In order to add practical understanding to the terms in this section, we will briefly define a few terms as they relate to collisions, and then look at some examples. Buoyancy, stability, and center of lateral resistance (CLR) are important concepts which will be explored in the next few sections.

7.3 Buoyancy

Buoyancy is particularly relevant to collisions because of the reactions of a stationary boat which is struck by another vessel. One of the key concerns in a two boat collision, especially one involving an over-ride, is the amount of reserve buoyancy available to the struck vessel. Reserve buoyancy is a measure of how much additional weight a vessel will support without sinking or being swamped. An aircraft carrier has a tremendous amount of reserve buoyancy, while a typical small bass boat does not. Boats with large amounts of reserve buoyancy may be characterized by having a high freeboard.

<u>Application</u>

When struck by another vessel, a boat with a small amount of reserve buoyancy will have an increased tendency to suffer from swamping, sinking, or at least temporary submersion in whole or in part during a collision.

7.4 Stability

A boat has both roll stability and pitch stability. Simply stated, stability tells us how hard it is get a boat to roll, or pitch when acted upon by outside forces. While this is not a precise definition, it should give you the general idea. A more technical definition is to say that stability is a measure of the forces generated by a floating body that develop to return it to its original floating position once it is disturbed. Most of the time, we are concerned about the roll stability of a boat. Roll stability is a measure of how hard or how easy is it to get the boat to heel over when acted on by an outside force.

In order to calculate the stability of a boat, we must know where the center of buoyancy is located. The center of buoyancy is the point through which the buoyant forces are acting. This point is the geometric center of the volume of the body which is submerged. We must also know the location of the center of gravity (CG) of the boat. In general, boats with a high CG and narrow beam are less stable than boats with a low CG and wide beam.

Naval architects will perform stability calculations to obtain the metacenter and the metacentric height, which is one indication of the stability of a vessel. We will leave the numerical calculations for stability to the naval architects, for most of what we are concerned with here is general trends and tendencies.The stability characteristics of a boat can be changed by how the boat is loaded. Boats with fly-bridges, or houseboats with upper decks become less stable as the weight aloft increases. A stationary boat with less roll stability will tend to roll more easily if struck from the side by another vessel.

7.5 Center of Lateral Resistance

What determines how a stationary boat moves or reacts when it is struck from the side? One of the key factors that determines the answer to that question is the location of the center of lateral resistance (CLR). Consider an outboard motorboat floating statically in calm water with the engine not running as shown in Figure 7-1a. We will assume for this example that the outboard motor is tilted up completely, so that none of its lower unit is below the waterline. If we could somehow push on the side of the boat in a horizontal plane perpendicular to the centerline, the boat should start to move sideways through the water. If we push on the boat near the bow at point A in Figure 7-1a, the boat would rotate about its CLR in a clockwise direction. If we gently push on the boat at point B, near the stern, the boat will rotate about its CLR in a counter-clockwise direction as illustrated in Figure 7-1b. If we repeat this experiment, and gradually shift the point where the force is applied more towards the midline of the boat, we will soon locate the point at which we can push the boat slowly sideways through the water without it rotating at all. The CLR is in line with this point, as shown in Figure 7-1c.

To continue with this example, we will now consider the same situation as in Figure 7-1c, except that we will lower the outboard down into its normal running position. The lower unit is now in the water but the boat is still stationary. If we continue to apply the force at point C, the boat no longer moves through the water sideways as it did in 7-1d. Instead it now rotates clockwise again. What happened? Figure 7-2 provides the answer. Figure 7-2a shows the location of the CLR with the outboard motor up. When the lower unit of the outboard was lowered into the water, the CLR shifted rearward just slightly as shown in Figure 7-2b. In reality, the difference for this example may be virtually undetectable, depending upon the ratio of the cross-sectional area of the outboard when compared to that of the submerged portion of the boat hull. The concept illustrated here is important. If we wanted to push the boat laterally through the water without any rotation occurring, we would have now have to push at point D, as shown in Figure 7-2b. The same effect could be created by adding weight aft, which changes the trim angle on the boat. If we added weight aft, for example by placing two passengers in the rear of the boat, the aft end of the hull would settle deeper into the water. This would move the CLR further aft.

How does one know where the CLR is located on the boat? It can be located by experimental means as described in our example. We can simply place the boat in the water and push on it sideways until we find the point at which it no longer rotates, but slides through the water laterally without rotation. That is not always practical. Notice that in Figure 7-2a the location of the CLR. It appears to be almost in the center of the profile of the submerged portion of the hull. For most powerboat hulls with hard chines, such as a typical tri-hull, the location of the CLR may be approximated by finding the geometric center, or the centroid, of the submerged cross sectional area of the hull. If it has been determined that this approximation is acceptable, then the CLR for complex underwater shapes may be calculated with relative ease for a given static floating position.

7.6 Movement of Boat Hulls in Directions Other Than Lateral

The importance of the word "lateral" in the discussion of the center of lateral resistance (CLR) must be emphasized. The CLR is that point about which the boat will tend to rotate if we attempt to gently push it through the water sideways, or laterally. When we try to push the boat through the water from the bow, the stern, or at some angle to the centerline, the center of LATERAL resistance is no longer the point in which we are interested.

Consider the stationary boat shown in Figure 7-3. The force applied at A will have the tendency to push the boat forward and cause slight rotation in a clockwise direction. It rotates about some point, similar in concept to the CLR, which we will call the center of hydrodynamic resistance (CHR). We will define the CHR as the point about which we can gently apply a force and move the boat

through the water in the direction of the applied force without inducing any rotation. Experimentation is the best method to determine this point for various applied points and directions. In Figure 7-3, the CHR is a point somewhere along the longitudinal centerline of the boat. It can now be stated that the CLR is simply a special case of the CHR.

Application

The CHR is one of the factors that determine the motion of the boat through the water when involved in a collision.

7.7 Weight, Mass, and Inertia

Since we will be discussing weight and mass extensively in chapters to come, it is worthwhile to quickly refresh the reader's memory on the difference between the two as it relates to our subject. All physical objects have mass. Objects have varying amounts of mass depending on the type and amount of material from which they are made. Mass can also be thought of as a relative measure of an object's inertia. The more mass an object has, the more difficult it is to get it to change its current state. For example, it requires more force to get a giant aircraft carrier moving from a dead stop, or to bring it to a stop once it is moving, than it does a 1500 lb. motor boat. Also, do not forget that from the equation

$$F = ma$$

that mass may be expressed as

$$m = \frac{F}{a}$$

which is consistent with the above example. We determine an objects mass from its weight by using the formula

$$W = mg$$

where g = the gravitational constant, or the acceleration due to gravity. On the earth's surface, the acceleration due to gravity is expressed as

$$g = 32.2\frac{ft}{sec^2}$$

Thus, the weight of an object is obtained by multiplying its mass times the value of g. Also note then that to obtain the mass of an object given its weight, we use the formula

$$m = \frac{W}{g}$$

Example:

What is the mass of a 2000 lb boat?

$$m = 2000 \frac{lb}{32.2 \dfrac{ft}{\text{sec}^2}}$$

$$m = 62.2 \ slugs$$

In the English system of units, the units of mass are given in slugs. The units of slugs are:

$$Slugs = \frac{lb\text{-sec}^2}{ft}$$

Weight is actually a force that results by placing an object with mass in a gravitational field. The weight of an object can change depending upon the strength of the gravitational field in which it is placed. The gravity on the moon is much less than what it is on earth, therefore an object placed on the moon's surface would weigh less than it does on earth, however its mass would remain the same. The units of weight are, of course, pounds, which we abbreviate lbs.

Inertia is an important related concept. A simple definition is that inertia is the tendency of an object to remain in its current state unless acted upon by an outside force. The more mass an object has, the more force it will take it to change its state. Inertia is the reason that you cannot cut the throttles on a 60 ft motoryacht 10 feet away from the dock while you are traveling at 20 mph, and expect not to have to contact your insurance company shortly thereafter.

A discussion on the scientific definitions of weight, mass, and inertia is left to various physics texts on the subject.

7.8 Center of Gravity

The location of the center of gravity (CG) of a vessel also plays a major role in determining how a vessel reacts during a collision. The CG may be located by finding the balance point for an object. It has long been known that finding the longitudinal location of the CG of a small boat may be easily accomplished by balancing the boat on a log or other object.

Newton's second law, expressed by F = ma, says that the total force applied at the CG of a an object is proportional to the mass times the acceleration at the CG. The location of the CG is critical because the CG is that point about which an object will rotate if the CG is not in line with the applied force. If the CG is in line with the applied force then the object will tend to move in the direction of the applied force without rotation. It is important to emphasize the force in the F = ma equation is the total resultant force. A complete analysis of all the forces can become extremely complex and difficult to analyze when we attempt to calculate the total resultant forces applied to a boat in the water involved in a collision.

7.9 The Effect of the CG Location in a Collision

The location of the CG plays a major role in determining the resulting motion of a boat when struck by another vessel. Its effects are analogous to those studied for the CLR in previous sections. To make certain we understand the effects of the CG location alone, let's place a flat bottom boat on a sheet of ice and strike it sharply as shown in Figure 7-4. The reactions are similar to those effects shown in Figure 7-1 for the CLR. When the boat is struck behind the CG, it tends to rotate counter-clockwise as shown in Figure 7-4a. It rotates clockwise when struck forward of the CG as shown in Figure 7-4b. When the impact is in line with the CG as shown in Figure 7-4c, then there is no rotation. In each of the above examples, the boat is not just rotating about the CG as if a nail were driven through the boat at that point. The CG is also moving sideways or laterally. Remember that the above is true for any object, not just boats. In this example, the boat is sitting on a sheet of ice because, for the sake of illustration, we wanted to show the effects of the CG location alone. The problem with this explanation is that most boat collisions do not occur on a sheet of ice.

7.10 The Combined Effects of CG and CLR, an Overview

The relationships between the CG and the CLR are important because they determine the center of rotation (CR) of a vessel during a collision. Generally, during a collision, a vessel will move laterally and may tend to rotate as well. The point about which the vessel rotates determines much about the resulting motion of the occupants and objects inside the boat. When the CLR and the

CG are found in the same vertical line on a boat, the center of rotation is also at that same point. When the CLR and CG are at vastly different locations, finding the center of rotation is much more complex and may vary depending upon the dynamic rates at which the boat responds to the applied forces. The locations of the CR in most situations for a dynamic impact is probably best determined by experimentation.

Application

If a boat is struck from the side, it will translate laterally through the water if it is struck at a point in line with the CR. If it is impacted forward or aft of the CR, it will rotate as well as translate. The location of the CR for a particular scenario is determined by the location of the CG, CLR, and the hull shape.

7.11 Kinetic Energy Defined

Kinetic energy is the energy of motion. When a boat is moving through the water, or a car is traveling over the road, it has kinetic energy because of its motion.

The kinetic energy of a body due to its motion relative to a fixed reference frame is defined by:

$$KE = \frac{1}{2} mV^2$$

KE = Kinetic Energy
m = mass
V = velocity

In words, the above equation says that the kinetic energy of an object due to its motion is equal to one half of its mass times its velocity squared.

This equation tells us that the energy of an object increases as a function of the square of its velocity, and linearly with regard to an increase in mass. In other words, if boat A has twice the mass, (and therefore twice the weight) of boat B, then boat A will have twice the kinetic energy of boat B for a given speed. It also means that if boat A and boat B have the same mass, (and therefore the same weight) but boat A is traveling twice as fast as boat B, then boat A has four times the kinetic energy of boat B.

Objects that rotate also possess rotational kinetic energy due to their rotational velocity. The propeller and the flywheel on the engine of a boat both have kinetic energy due to their rotation. Typically, the kinetic energy due to rotation is assumed

to be negligible compared to that due to the object's motion. We are going to neglect the effects of rotational kinetic energy in this document.

Kinetic energy is an important concept to understand because it determines how much energy is available in a collision. One practical application of this concept is that the kinetic energy available is an important factor in determining the capacity of an impact to cause damage. When a boat collides, either with an object or with another boat, some or all of the kinetic energy will be dissipated. During an impact of a boat with a seawall, kinetic energy is typically converted to several forms of other types of energy such as heat, sound, and possibly light. It may also be used to deform, break, and crush the structure of the boat, and the object struck. If the boat retains some of its speed and continues to travel after the impact, then not all of the kinetic energy was dissipated in the impact.

Application

The kinetic energy increases proportionally to the velocity squared. The kinetic energy of a boat is one factor that determines the capacity of that boat to cause damage in a collision, either to itself or the object struck.

Example:

What is the kinetic energy of a 2,000 pound boat traveling at 15 mph, and 30 mph?

First, we must find the mass. From our earlier example, we know the mass of a 2,000 lb boat is 62.1 slugs. This comes from the formula:

$$m = \frac{W}{g}$$

The next step is to convert speed from mph into ft/sec.

The relationship between ft/sec and mph is as follows is shown below:

To change from mph to ft/sec:

$$\frac{(1\ mile)\ (1\ hour)\ \ (5280\ ft)}{(\ hour\ )\ (3600\ \mathrm{sec})\ (mile\ \ )} = \frac{1.46667\ ft}{\mathrm{sec}}$$

Therefore, to convert mph to ft/sec multiply by 1.46667.

To change from ft/sec to mph divide by 1.46667.

Numerous instances will occur in this document where we need to convert from mph to ft/sec and back again. If you forget the above formulas, all you have to remember is the number 1.46667 and that the number in units of ft/sec is always a larger number than that for mph.

Now let's return to our example of finding the kinetic energy of a 2,000 lb boat traveling at 15 and 30 mph.

The velocity in ft/sec is then:

$$V = 15\ mph\ x\ 1.46667 = 22\ ft/\text{sec.}$$

The kinetic energy at 15 mph is therefore:

$$KE = \frac{1}{2}\ (62.11\ Slugs)\ (22\ ft/\text{sec})^2$$

$$KE = 15{,}031\ ft\text{-}lbs$$

The kinetic energy at 30 mph is then:

$$KE = \frac{1}{2}\ (62.11\ Slugs)\ (44\ ft/\text{sec})^2$$

$$KE = 60{,}122\ ft\text{-}lbs$$

Note the units of kinetic energy are ft-lbs (not the same as ft/lb). Also note that as the speed doubled from 15 to 30 mph, that the KE increased by a factor of four. Thus the KE of an object increases proportional to the velocity squared.

7.12 Potential Energy

Energy is important, and comes in many forms. In order to understand how it is possible to estimate speeds in certain types of collisions, it is necessary to understand the concept of potential energy. Potential energy is stored energy due to an object's location or position in a system. Potential energy comes in many forms, including the stored energy in a spring. For our case, we are primarily concerned with potential energy defined as that related to an object's position in a gravitational field. Practically speaking, the higher an object is to some reference point, such as the surface of the earth, the more potential energy it possesses.

Kinetic energy and potential energy are easily converted from one form to another. If an object is at the top of a table, and at rest, it has zero kinetic energy, and a certain amount of potential energy. If we drop that object from the table top, it gains a certain amount of kinetic energy, and loses a certain amount of potential energy as it falls. A definite relationship exists between the rate at which an object gains one form of energy and loses the other. In an ideal system, with no outside forces acting other than gravity, then the net change in kinetic energy plus the net change in potential energy must be equal to zero. This is expressed as:

$$dKE + dPE = 0$$

where d represents change in the quantity it precedes. This concept of the conservation of energy is what will allow us to calculate boat speeds in certain types of collisions.

In the previous section, we saw how to quantify kinetic energy and now we will look at how to calculate the potential energy of an object.

$$PE = mgh$$

where
m = mass
g = gravitational constant
h = height in feet w/ respect to reference frame

The potential energy then, is expressed as the mass of an object times the gravitational constant, times the height in feet (of the CG) above the reference frame. The reference frame for our case may be the surface of the water or some other point in question.

Application

What is the potential energy of a 2000 lb boat which is sitting on a pier such that the CG is 12 feet above the surface of the water?

Relative to the water's surface, the potential energy is:

$$PE = mgh$$

$$PE = (62.1\ slugs)\ (32.2\ ft/\text{sec}^2)\ (12\ ft)$$

$$PE = 23{,}995\ ft\text{-}lbs$$

Note that the units of potential energy are derived from (slugs) (gravity) (height) which is :

$$\left[\frac{lb\text{-}sec^2}{ft}\right]\left[\frac{ft}{sec}\right]\left[\frac{ft}{1}\right]$$

which leaves units of ft-lbs. The units for potential energy are the same as for kinetic energy.

Potential energy and kinetic energy therefore contain the same units. In chapter 11, we will see how to use these concepts to estimate minimum boat speed for certain situations.

7.13 A Deeper Look at Concepts of Impact

7.13.1 Sequence of an Impact

When two objects collide, a series of events occurs that can be broken down into three distinct phases. These phases are first contact, maximum engagement, and separation. The contact force is, of course, zero just prior to first contact and just after separation. It is true that in boat collisions, separation does not always occur. Automotive reconstructionists have often used these terms to describe automobile accidents and they generally apply here as well. The three phases of a typical collision are:

First contact - That point at which surfaces of the two colliding bodies begin to touch. The impact force begins to increase at this point in time. Just prior to first contact, the impact force was zero.

Maximum engagement - Maximum engagement is that point in a collision where the greatest penetration of one vehicle into the other generally occurs. In a direct impact, the velocity of the object struck and the colliding vehicle will be zero relative to each other at maximum engagement.

Separation - Generally after maximum engagement, the impact forces begin to decline, and the objects which have collided will begin to separate from each other. When the objects are no longer in contact with each other, the impact forces will go to zero.

Maximum engagement in car collisions is relatively easy to define, partly because of the way vehicles usually collide, and partly because they retain their shape after a collision. However, determining the positions of one boat relative to another at maximum engagement in a small boat collision is not an easy task.

7.13.2 Types of Impact

The automotive community has classified impacts into one of two basic types:

Full Impact - A full impact occurs when the two surfaces in contact reach a common velocity, i.e., they are not sliding against each other. The two object may still be traveling in reference to the ground or some fixed reference, but they at least, for an instant, reached a common velocity. Imprints of one surface on another are most likely with full impacts.

Partial Impact - A partial impact is one in which the surfaces in contact are always moving against each other. Damage such as striations and paint transfer will indicate the relative direction of one surface relative to another.

Contact forces during a partial impact are likely to be less than for a direct impact. During a partial impact, separation of the boats will occur, and one or both boats will have a certain portion of their initial kinetic energy remaining. Since not all of the energy was dissipated during the collision, it may be generally concluded that partial impacts will result in lower contact forces than direct impacts.

Most small boat collisions involving two boats are partial impacts. All over-ride cases where the boats separate will be partial impacts. The rare exceptions to this fall into one of two common types of accident scenarios.

The first is where both boats are traveling in approximately the same direction, but on a converging course. At the last instant, one or both operators turns away to avoid a collision and the sides of the boats gently bounce off each other. The second common scenario is where one boat literally runs into and penetrates the second boat, and then stops. Collisions with fixed objects may be either full or partial impacts. Partial impacts tend to leave long scrapes, striations, and paint transfers, and direct impacts tend to leave imprints.

7.13.3 Magnitude of Impact Forces

One of the significant differences between boat and auto collisions is the magnitude of impact forces. To date, no testing has been done to scientifically measure impact forces during a small boat collision. It is valuable to note the likely differences between the magnitude of impact forces between automobiles and small boats.

The actual impact forces and corresponding decelerations for two boat collisions are probably less than for automobiles for the following reasons (in approximate order of importance):

1. Small boat collisions are generally partial impacts, where one or both boats retain a significant portion of their original speed.

2. Boats generally travel at lower speeds than automobiles. For example, 30 mph is considered a high speed boating collision, while a normal highway speed for automobiles may be 65 mph.

3. Small boats often weigh less than their land based counter parts, thereby possessing less kinetic energy for a given velocity. Of course, this is not always true.

4. The structure of the boat involved in a collision is usually softer and more flexible than the body of an automobile.

It is important to emphasize that the above generalities primarily apply to cases where one boat collides with another, not collisions with fixed objects.

7.13.3.1 Significance of Impact Forces

One may tend to think that if the impact forces are lower in boat collisions than for autos, that boat collisions, in general must not be as severe as automobile collisions. In order to put this into perspective, consider an extreme analogy. If a passenger train ran head-on into a freight train, we would definitely have potential for very high impact forces sufficient to cause injury to the train operators and passengers. Conversely, if the same passenger train ran off the tracks and plowed through a wooden frame house, it may lose only a slight amount of kinetic energy as it converts the structure into sawdust. The impact forces and corresponding accelerations in this case would be considerably less. Is this a less dangerous impact? Perhaps it is to the train operator but not to those who live in the house!

Remember the following basic formula from our friend Newton:

$$F = ma$$

This formula tells us that if the impact forces between the two boats are lower, then the corresponding accelerations will be lower also. This, in itself, is good news. Many injuries in automobile accidents are caused by the occupants slamming into various interior portions of the vehicle as it accelerates or decelerates violently due to large impact forces. This large

impact force may be the result of being struck by a second vehicle or from the vehicle striking a fixed object. The good news for the boater is that it appears that the occupants in a stationary boat are not as likely to be injured by having their boat violently jerked out from under them as perhaps they would in a car. This is because lower impact forces result in correspondingly lower accelerations.

The bad news is that an impacting vessel can strike a second boat and penetrate the sides and interior in such a way as to make contact with the occupants directly. The results here can be fatal.

From the observance of experimental collisions, it appears that some of the highest potential for serious injury due to sudden changes in acceleration of a vessel occur in over-ride situations. The impacting vessel has two opportunities to experience significant decelerations. The first is during impact with the other vessel. The amount of deceleration experienced by the striking vessel at impact is related to the quantity and strength of structure on the other boat through which the striking boat penetrates. The velocity of the striking boat may decrease only slightly during the impact or it may go to zero.

The second opportunity for serious injury from rapid accelerations to occupants of the striking boat is upon re-entry into the water. During a high speed over-ride accident, the striking boat may be launched high into the air. It may re-enter the water with sufficient vertical velocity to injure its occupants upon impact. These re-entries have created sufficient forces to crack boat hulls, separate hull and deck joints, and break seat mountings.

7.13.4 Impact Forces - Point of Application

During a collision, the point of application of the impact force relative to the CG helps to determine the subsequent motion of the boat. We want to look at the general case of how this applies to any object before we look at the specifics of boats. With respect to the location of the impact force, the impact is classified as either a centered impact or an eccentric impact.

Centered Impact - A centered impact is one in which the impact force is in line with the CG of the struck object. The result is a change in velocity. The struck object does not rotate.

Eccentric Impact - An eccentric impact is one where the impact force is not in line with the CG of the struck object. As a result, the struck object changes velocity and rotates.

The application of this principle for automobiles is well known in automobile accidents and is shown in Figures 7-5 and 7-6. Figure 7-5 shows possible locations where an impact force could be

applied and still be a centered impact. Each of these forces would pass through the CG of the auto and will not induce any rotation. Note that the actual distance of the point of application of the force from the CG does not have any effect on the resultant action for a centered impact.

Figure 7-6 shows possible locations for the impact force that will result in an eccentric impact. Random circumstances would be much more likely to produce an eccentric impact than a centered impact. In practice, field experience has shown that eccentric impacts are much more common in automobiles than centered impacts. Even head on collisions, which are usually thought of as centered impacts, often involve some eccentricity that causes a misalignment of the impact forces with the CG. A true centered impact is rare. Note that in Figure 7-6 that a moment (torque or turning action) is produced about the CG by any of the impact force locations. The magnitude of the moment determines how quickly the vehicle will rotate.

7.13.5 Torques and Moments

A moment is simply a torque or a turning force. A moment about an object, or the torque applied to an object is technically defined as the force times the perpendicular distance of the line of action of the force from the CG of the object. In Figure 7-6, if F1 and F2 are of equal magnitude, then the F2 would produce a higher rotational velocity than F1, all other things being equal. Note that the torque is not determined by the distance of the point of application of the force from the CG, but the distance of the line of application of the force from the CG. Figure 7-7 illustrates the difference.

This difference is important because of the tendency of the novice to assume that the farther away from the CG the force is applied, the greater the moment and hence the corresponding rotational speed. Figure 7-7 shows forces F1 and F2, both equal to 5000 lbs of force. The actual distance of the point of application of the force F1 from the CG is represented by D. This distance has no bearing on the moment produced by F1. The distance C is the horizontal component of the distance of F1's point of application from the CG. This distance is not the same as the perpendicular distance which is required for the calculation, thus the value of C alone has no bearing on the value of the torque applied by F1. The real distance to be concerned with is represented by A, which is the distance between two parallel lines. One parallel line passes through the CG parallel to a second line which is the line of force F1.

In Figure 7-7, you can easily find the perpendicular distance of F1 from the CG by performing the following steps:

A. Extend a line through the CG so that it is parallel to F1.

B. Measure the distance between the two parallel lines. You should use a right angle such as found on a right triangle for accuracy. The two parallel lines are always the same distance apart, so the distance between the two can be measured at any point.

Let's go back to Figure 7-7. The torque or moment produced by F2 is the product of F2 times B, which is the perpendicular distance to use for the calculation of torque for F2. Here we see that the torque produced by F2 about the CG is greater than that produced by F1, even though it appears that F1 is farther away from the CG.

The main point to remember is that for a given impact force, the magnitude of the moment produced by that impact force is determined by the perpendicular distance of the line of action of that force from the CG. It is not determined by how far away from the CG that force is applied.

High impact forces applied to automobiles can send a vehicle spinning across the highway at high rotational speeds. Rotational speeds as high as 300 to 400 degrees per second are attainable and the vehicle may make several complete rotations before coming to a rest. This is possible due to the limited friction forces applied by an automobile's tires.

7.13.6 Impact Forces as Applied to Boats

In automobile collision analysis the impact force is not the only force to be considered. The friction forces between the tires and the road surface are present to varying degrees depending upon the particular situation. Virtually all texts on automobile accident reconstruction neglect tire forces during the analysis of the actual impact. This has proven to be an acceptable simplification for most situations, because the impact forces are generally orders of magnitude greater than friction forces generated by tires on the road surface. It is also a very convenient simplification since it is difficult to analyze the actual tire forces during a real-time collision. Engineers and scientists often make these types of assumptions and simplifications in the early stages of solving complex problems to get to the heart of the problem. As additional knowledge and data become available, the details are supplied. To conduct an analysis of boat collisions, we too will have to make some assumptions and simplifications wherever possible. The difficult part is knowing in the early stages, what assumptions can be made without destroying the validity of the phenomenon being studied!

The concepts of the previous section most certainly apply to boats as well as cars. Boats experience impact forces and moments during a collision just as automobiles do. The careful investigator will also note that boats seldom have tires and cars do not float (no doubt there have been a few exceptions). How then are the applications of these concepts different for boats?

A boat sitting stationary in the water can be impacted by a second vessel traveling at high speeds so as to create the maximum possible moments, and it may or may not experience a rapid rotation. The boat will certainly tend to rotate, but the resulting rotational velocity is not easy to predict. From observation of un-instrumented experimental collisions, it appears that the dampening effect of the water will quickly slow the rotational velocity to values that are virtually negligible almost immediately after the two vessels are no longer in contact. High rotational rates during the actual impact are likely to be achievable. Were it not for the hydrodynamic forces, i.e. the dampening effect of the water, the rotational velocities would certainly be greater.

7.13.7 Impact and Thrust Direction

This section would not be complete without discussing thrust direction. Some texts also refer to it as principle direction of force. Simply stated, it is the thrust direction that determines why objects bend and shift in a certain direction during the impact. Automobile reconstructionists generally assume that the thrust can be considered to be concentrated at the point of maximum penetration, which is usually the position of maximum engagement. For autos, this is probably true. If one had to plot a force vs. deflection curve for an automobile body, it would certainly always have a positive slope. The outer structure of an automobile will continue to offer some kind of resistance to further penetration by an outside force.

A boat hull however, behaves more like an eggshell in a collision rather than a solid object. The outer perimeter offers an initially strong resistance to penetration, then gives way entirely. This is especially true for a vessel struck from the side. The point of maximum engagement in an over-ride accident is probably not the point of highest impact forces. A force vs. deflection curve for a boat hull, especially with an impact force applied from the sides, may not always have a positive slope. It is perhaps more accurate to think of Figure 7-8 as a force vs. penetration distance curve. Figure 7-8 illustrates this concept for an automobile. Here we see that the force F, required to crush the front of the vehicle is proportional to the crush distance D. A common accident reconstruction technique in automobile accidents is to use the crush energy required to deform a vehicle a certain amount to estimate the speed of the vehicle at the time of the impact. Figure 7-9 shows that the distance which an object penetrates a boat hull is not necessarily proportional to the penetration distance. For an open motorboat, once penetration of the initial side is complete, there may be little or no structure which resists further penetration except for the opposite hull side.

The thrust direction may change during the course of an impact. Determining the thrust direction can be important in determining the relative angles of impact. Thrust direction in

automobiles can be determined in automobile accidents by carefully analyzing the physical damage to the vehicle. With boats, it is not so easy. Because fiberglass has the tendency to break loose during impact and then spring back into position, it is difficult to examine a boat and determine the thrust direction. If the boat struck a stationary object, the thrust direction will be the direction opposite of the boat's direction of movement. Note that the direction of movement may or may not be the same as the direction in which the boat was pointed. The boat may have been skidding across the water slightly if the operator had made a hard turn to avoid the object. Also, if the impact was eccentric, resulting rotations may leave damage patterns that hide the initial thrust direction.

When two boats collide, the thrust directions for each boat act in exact opposite directions from each other. Remember that this direction may change as the impact progresses. The thrust direction may sometimes be determined by the location of objects which have shifted location from their original position. Determination of which direction occupants were thrown can also help to determine thrust direction. These techniques work well in autos, but once again in boats, caution is warranted.

The problem with using the location of shifted objects and the motion of occupants is that rotation during a collision will alter the location of these objects such that what is seen is the combined result of both rotation and translation. At this point in our capability, it is not possible to separate which components of the motion were due to rotation and which were due to translation. Thus, without additional data, the true thrust direction remains an uncertainty.

Figures 7-10 and 7-11 illustrate that there can be many combinations of forces and resulting motions that produce the displacement of an object.

Figure 7-10 is one of the few examples of a true centered impact without rotation which is likely to occur in the boating arena. In this diagram, a boat has collided with a seawall head-on. The direction of thrust really is opposite to the direction in which the object shifted. We see that the cover of the motor slid forward as a result of the impact.

Figure 7-11 is a more likely scenario. It is a theoretical case involving extremely rapid vessel rotation. One might be tempted by examination of the direction of the shifted engine cover to incorrectly determine that the thrust direction was that indicated by the arrow at T1. We have two clues in the drawing as to why this may not be an accurate assessment.

First, if the thrust direction were that as indicated by T1, the impact would be eccentric, thus normally resulting in some rotation. This would immediately cause us to re-evaluate what the true thrust direction must have been since rotation likely occurred. We would also expect to see damage at T1.

Second, and more obvious, the damage to the starboard bow of the vessel indicates that this was the point of impact. Let's assume then that the thrust direction was that indicated by T2, and that the weight of the bullet boat was sufficient to press down the front end of the boat in the figure significantly. The resulting shift in the CR (center of rotation) may have made it possible for the engine cover to shift in the direction indicated. For this to have occurred, the local velocity of the aft end of the boat must have had a component in the positive x direction! Future testing is needed to confirm that this is really possible, but it appears theoretically achievable.

The examination of shifted objects indicates the relative direction of the total acceleration vector of that part of the boat. This piece of information is valuable in ascertaining the resulting motions of a vessel during an impact.

It is important to remember that the direction an object actually shifts during a collision is partly determined by how it is secured. The engine cover may have been preventing from shifting in a direction exactly opposite of the local acceleration of that component of the boat by other objects in the way or by the way its fastening means failed.

Do not be confused by relating the direction of shift to local acceleration rather than local velocity. It is a change in velocity, which is by definition acceleration, that creates the forces which cause an object to shift. The direction of shift is an indication of local accelerations, not local velocities.

7.14 Friction and Hydrodynamic Resistance

7.14.1 Friction

We all know that when we try to slide one object over another, there is some force that tends to resist that sliding motion. This force is known as friction. The basic friction forces generated between any two objects in contact are based on classic friction theory. This theory states that the friction force produced by two surfaces in contact is equal to the coefficient of friction times the normal contact forces between the two objects. Mathematically, it is expressed as follows:

$$f = uN$$

f = friction force
u = coefficient of friction
N = Normal forces

Friction is important from the perspective of analyzing boat collisions in two particular applications:

1. Whenever an over-ride situation occurs, the two boats are at least momentarily sliding across each other. Some of the kinetic energy of one or both boats is lost due to friction.

2. When a boat runs up onto shore, or slides over any consistent surface such as a boat ramp, dock, or even another larger boat, kinetic energy is lost due to friction.

In the first case, the energy lost due to friction may be insignificant. In the second case, much of the kinetic energy is lost due to friction and may be used to estimate the impact speed of the boat.

The second case is not unlike estimating the speed of an automobile based on the length of the skidmarks, the grade of the slope and the coefficient of friction.

7.14.2 Hydrodynamic Resistance

Just as there is friction when one object slides across another, so there is resistance when a boat or other object is moved through the water. The value of the hydrodynamic resistance of a submerged body in a fluid depends on many factors, but of primary importance are the shape of the object, the projected area, and the flow velocity. Any boat moving through the water has to push a certain amount of water out of its way in order to travel. This resistance and its magnitude are not generally of great concern with regard to collision analysis of small boats.

The hydrodynamic resistance which concerns us in collision analysis is that which acts on the hull in a direction opposite the impending motion. The hydrodynamic resistance plays a role in determining vessel reactions. There are three distinct scenarios which are worth considering with regard to the affects of hydrodynamic resistance. We will look in more detail at a stationary boat, a boat fully on plane, and a boat at "hump" speed just beginning to come up on plane.

7.14.2.1 Hydrodynamic Resistance Effects for a Stationary Boat

When a stationary vessel is struck from the side, the hydrodynamic resistance prevents the hull from sliding rapidly through the water sideways. We saw in section 7-6 how the hydrodynamic resistance acts through the CLR for a stationary boat. The magnitude of the resistance is important for it plays a role in

determining the corresponding lateral acceleration experienced by the struck boat. In a centered impact, the lateral acceleration experienced by the boat in Figure 7-12 may be expressed as

$$F_{net} = ma$$
$$F_i - F_h = ma$$

where F_i = impact force
F_h = hydrodynamic resistance
F_{net} = net force, or resultant force

Based on the above equations, consider the effect of a change in the lateral resistance alone. The value of F_h may be relatively low or relatively high depending upon the boat's design.

Examples of boats with relatively low lateral resistances may include small rowboats, flat bottom boats, canoes, jon boats and many small motorboats. Small sailboats with their daggerboards or centerboards in the up position would also have low lateral resistances.

Boats with relatively higher lateral resistances would include deeper draft boats of all types, including V-hulls, heavier tri-hulls and sailboats with fixed keels or smaller sailboats with daggerboards or centerboards lowered.

During a centered lateral impact, where the impact force is in line with the CR, a collision with a target boat with a low lateral resistance may exhibit characteristics that are different when compared to an impact with a target boat with a higher lateral resistance. For example, a struck (or target) boat in a centered lateral collision as shown in Figure 7-12b may exhibit the following characteristics:

a. Increased values of lateral acceleration;

b. Decreased peak contact forces between the boats during collision;

c. Less impact damage;

d. Slightly decreased chances of over-ride/penetration occurrence;

e. Increased chance of injury to occupants due to secondary collision with boat interior

f. Increased chance of occupants being thrown from the target boat due to the greater acceleration values.

For this example, we are assuming that the target boat has a velocity of zero, that is, it is stationary in the water. These characteristics would also likely be true when the target boat is moving, but is not yet on plane. Once a boat is on plane the above characteristics may not be true at all. The degree to which any of these characteristics becomes apparent in a particular collision is dependent upon many factors other than just the lateral resistance of the hull. All other things being equal (which they never are), the above tendencies should remain true when the impact with a boat with a low lateral resistance is compared to the impact of a boat with a relatively high lateral resistance. The extreme scenario for this example would be for the struck boat to have almost zero lateral resistance. This would be virtually equivalent to having the boat sit on a sheet of ice when struck. In reality, even the most shallow of boats will have a significant amount of lateral resistance when struck from the side by another vessel.

For light weight boats with a low lateral resistance, accelerations of the struck boat can be fairly great, and yet the resulting visible damage may be slight. The explanation in simplistic terms is that since the struck boat is able to move more easily out of the way of the bullet boat, due to low mass and low lateral resistance, the impact forces may remain relatively small, thus causing minimal damage. In this scenario, more of the impact force is absorbed by the target boat as kinetic energy rather than damage. This would not be the case if a boat with greater lateral resistance, such as a full keeled sailboat, was struck.

This concept is more aptly explained by understanding the relationship of impulse to momentum. The impulse is equal to the integral of the force over the contact period and it determines the corresponding change in linear momentum of the object struck. Since the boat with a lower lateral resistance is in contact longer with the struck boat, the peak contact forces may be lower and still achieve the same total impulse. The value of the impulse may be derived graphically by finding the area of the force vs. time curve. Figure 7-13 shows two theoretical graphs of force vs. time curves that illustrate this effect. The actual values for a collision are unknown since, as of this writing, these forces have never been measured in a boat collision.

It is important to note that we could have listed only the characteristic in (a) above. Everything else is an obvious repercussion. The characteristics listed in (b) through (f) above are all results of the increase in lateral acceleration of the struck boat.

The trends for the striking vessel involved in a centered lateral impact with a target boat with a relatively low lateral resistance should now be clear. When a vessel is involved in a collision of this type, the bullet or striking vessel may exhibit the following characteristics:

a. Lower values of longitudinal deceleration;

b. Decreased peak contact forces between boats during impact;

c. Less impact damage;

d. Less chance of over-ride/ penetration;

e. Decreased chance of injury to occupants of the striking boat due to secondary collisions with boat's interior;

f. Decreased chance of occupants of striking boat being thrown into the water.

The only difference between the listed characteristics of the striking boat and the target boat is the change in acceleration experienced by each. The striking vessel, in this example, should experience a slight decrease in longitudinal deceleration at impact. The resulting tendencies related to occupant motion are a direct result.

Consider what happens to the struck boat in the same scenario, if that boat now has a large lateral resistance. The opposite characteristics should be present. To be specific, the characteristics experienced by the target vessel, during a centered lateral impact which has a relatively high lateral resistance, are as follows:

a. Decreased values of lateral acceleration;

b. Increased contact forces between the two boats during impact;

c. More severe impact damage;

d. Increased chance of an over-ride, and/or penetration;

e. Decreased chance of injury to occupants due to secondary collisions with boat's interior; however, there is now an increased chance of injury due to direct contact with the bullet boat or related debris (if penetration occurs);

f. Decreased chance of occupants being thrown into the water due to decreased lateral accelerations.

Once again, this example assumes that the struck boat is stationary in the water and struck from the side. The tendency toward over-ride vs. non-over-ride impact as it relates to the lateral resistance is speculative and subjective at this point. The magnitude of the effect of the lateral resistance and these tendencies toward over-ride is difficult to quantify and needs to be evaluated by further testing before definite conclusions are made.

The examples used in this section also parallel the effects of increased vs. decreased mass of the struck boat. That is, the boat with the lower mass will tend to accelerate more rapidly during impact and the boat with significant mass will accelerate more slowly. The characteristics listed above for a boat with a low mass are comparative to those of a boat with a low value of lateral resistance. Conversely, the characteristics listed for a collision of a boat with a large mass are parallel to those listed for a boat with a large lateral resistance.

7.15 Friction and Hydrodynamic Resistance in Collisions

While it may be generally valid to neglect tire friction forces in automobiles, it is probably not valid to neglect hydrodynamic resistances in boat collisions. The closest equivalent of friction of tire forces on a boat is the hydrodynamic resistance of the water in which it floats. These forces are very different from friction produced by automobile tires. Friction produced by automobile tires is a predictable and relatively well known phenomenon. The maximum value of the friction force produced by tires during a collision is limited and is a function of the coefficient of friction between the two surfaces, and the load placed on the tires. The point of application of the tire friction forces to the automobile is always known since it must be transmitted to the vehicle through the axles and suspension.

Hydrodynamic forces during a two boat collision are different from tire friction in automobiles and exhibit some of the following characteristics:

1. There is no theoretical limit to the value of the hydrodynamic force based on the boat's weight.

2. The point of application of the hydrodynamic force may vary during the accident.

3. The magnitude of the hydrodynamic resistance during a collision is generally proportional to the speed of the boat hull through the water, and is therefore related to the mass of the struck boat and the impact force.

4. The magnitude of the hydrodynamic resistance is likely not negligible when compared to the impact forces on small two boat collisions.

5. During a two boat collision, as the mass of the target boat increases, the significance of the hydrodynamic forces decreases.

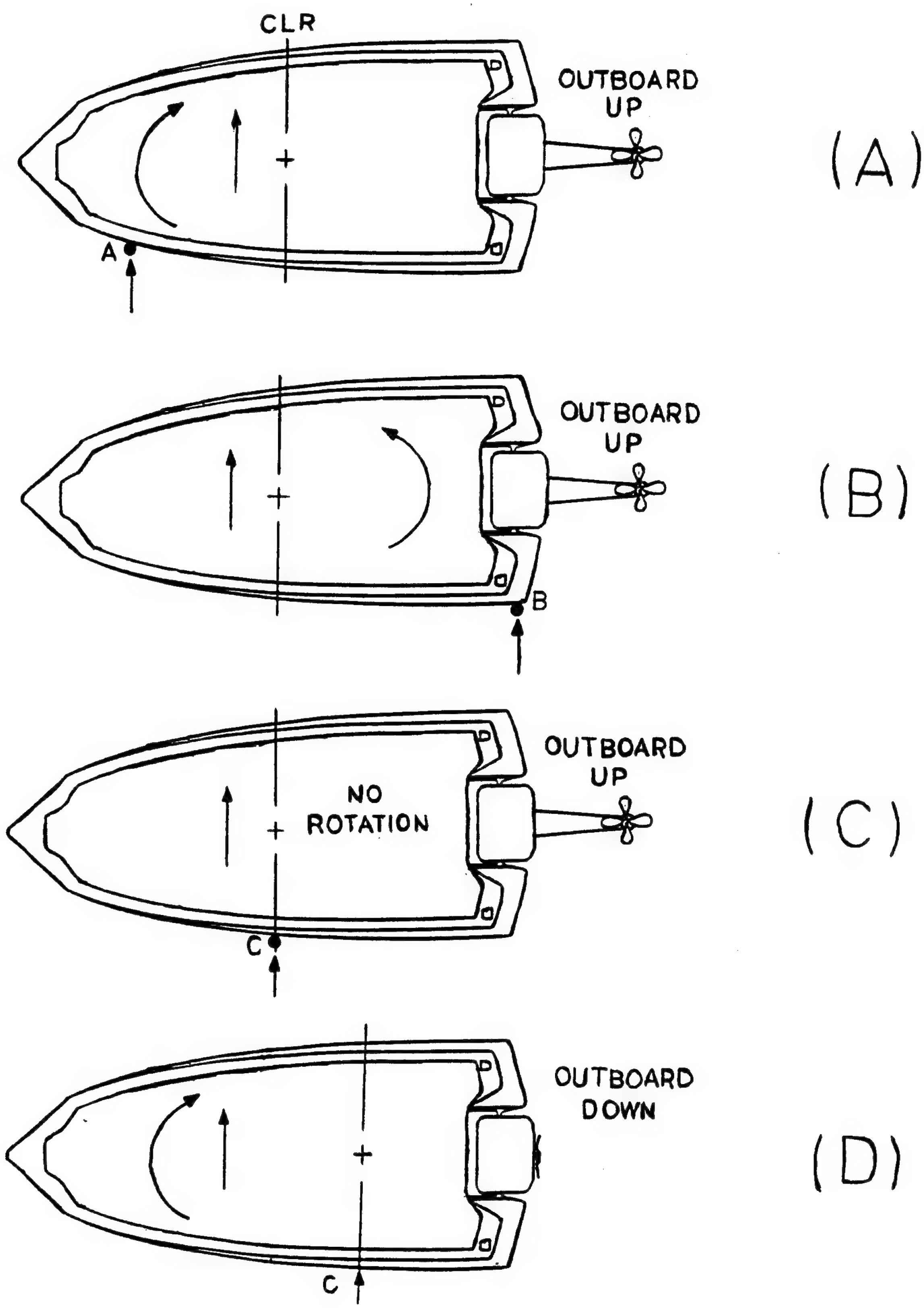
The above statements are hypotheses based on data accumulated thus far, and have not been verified by experimentation. If all of the above statements are true, one conclusion to be made is that hydrodynamic forces during a small boat collision are generally not negligible. Hydrodynamic forces are likely to be small whenever

the target boat does not tend to move through the water. Such cases occur when a small boat strikes a vessel with much greater mass. Another case is where the impulse of the impact force is applied over such a short time duration that the struck boat would not have likely moved much anyway. Examples of this would be cases involving a high speed bullet boat striking a stationary target boat and maintaining contact for a very small time duration. Another way to consider whether hydrodynamic forces were significant is to think about what might have happened if the two boats had somehow collided on land.

For example, if a 16 foot bass boat traveling at 70 mph strikes an 18 foot stationary ski boat from the side, and the resulting collision is an over-ride, would we expect the ski boat to move much? We will assume that the bass boat penetrated the first hull side and went airborne such that it cleared the second side.

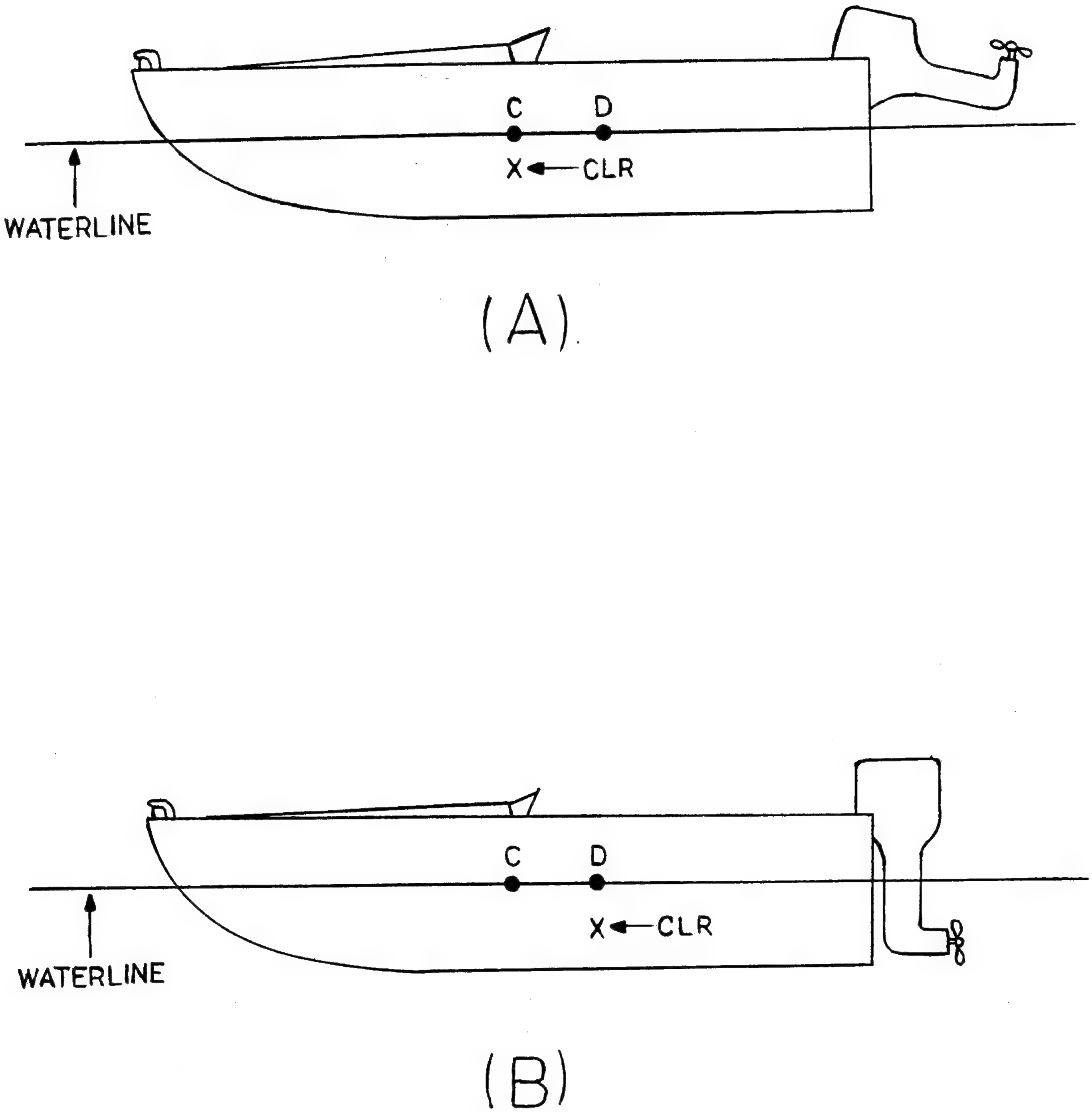
The key here is to realize that in an over-ride, the bullet boat is likely to retain much of its kinetic energy, which will also reduce the contact time with the struck vessel. Assuming that the 18 foot ski boat suffers damage only on one side, only a small amount of kinetic energy would have been lost. If this accident could have somehow occurred on a sheet of ice, it is still unlikely that the target boat would have moved laterally very much during the collision.

One of the questions that remain in the detailed analysis of boat collisions is just what effect the hydrodynamic forces have on both the target boat and the bullet boat. Hydrodynamic forces are one of the reasons that traditional impact methods used in automobile analysis have not proven useful for boats. Once a boat is struck and given some initial linear and/or rotational velocity as a result of the impact, that motion is immediately slowed and dampened by the water in which the boat floats. This is part of what makes the analysis of boat collisions so complex.



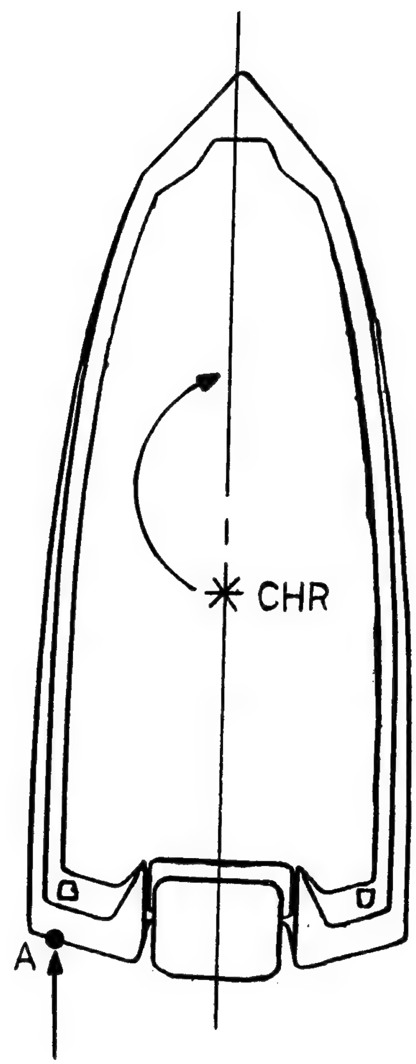
The Relationship of Lateral Forces and CLR Location to Boat Rotation

Figure 7-1



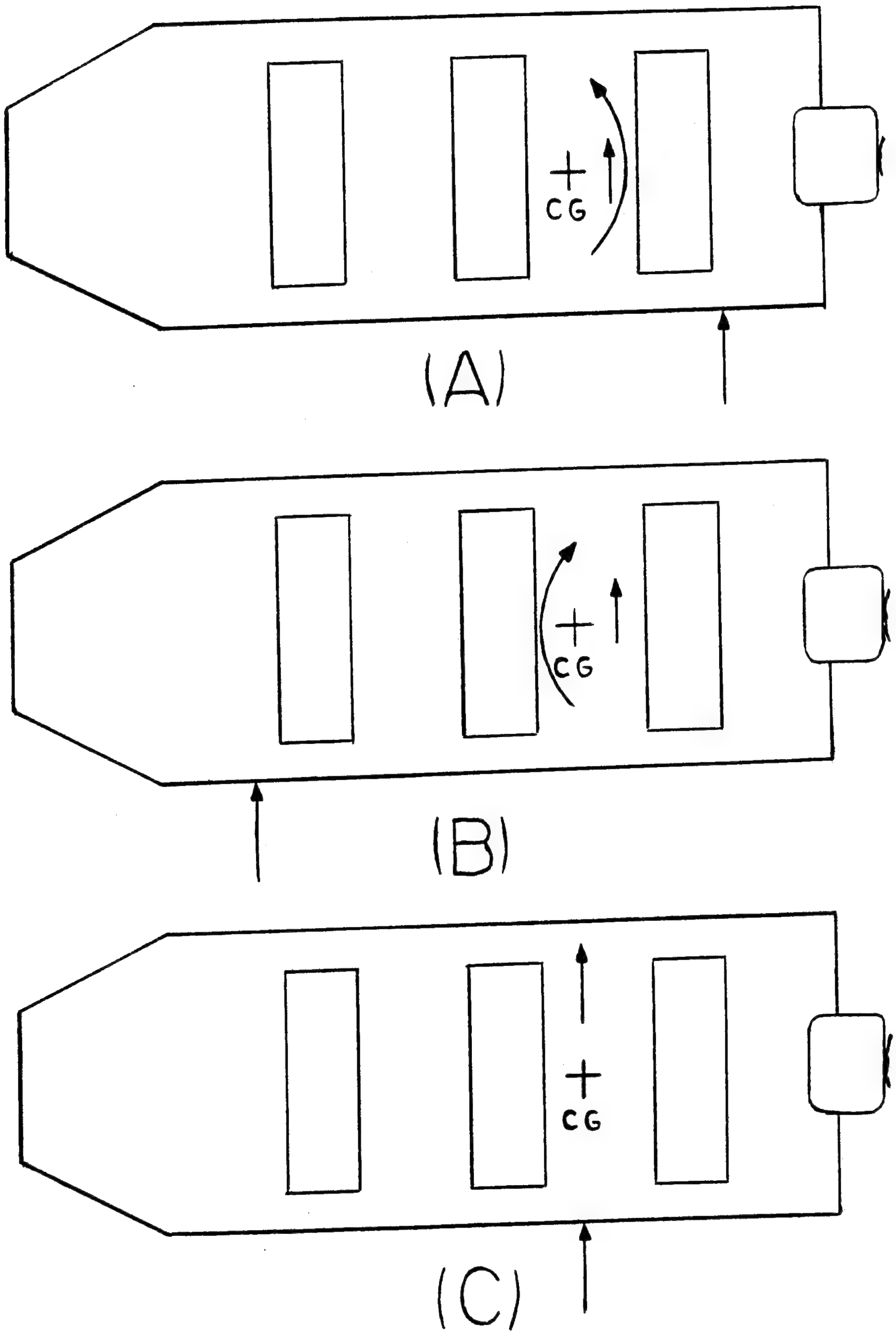
Lowering the Outboard Motor Changes the Location of the CLR

Figure 7-2



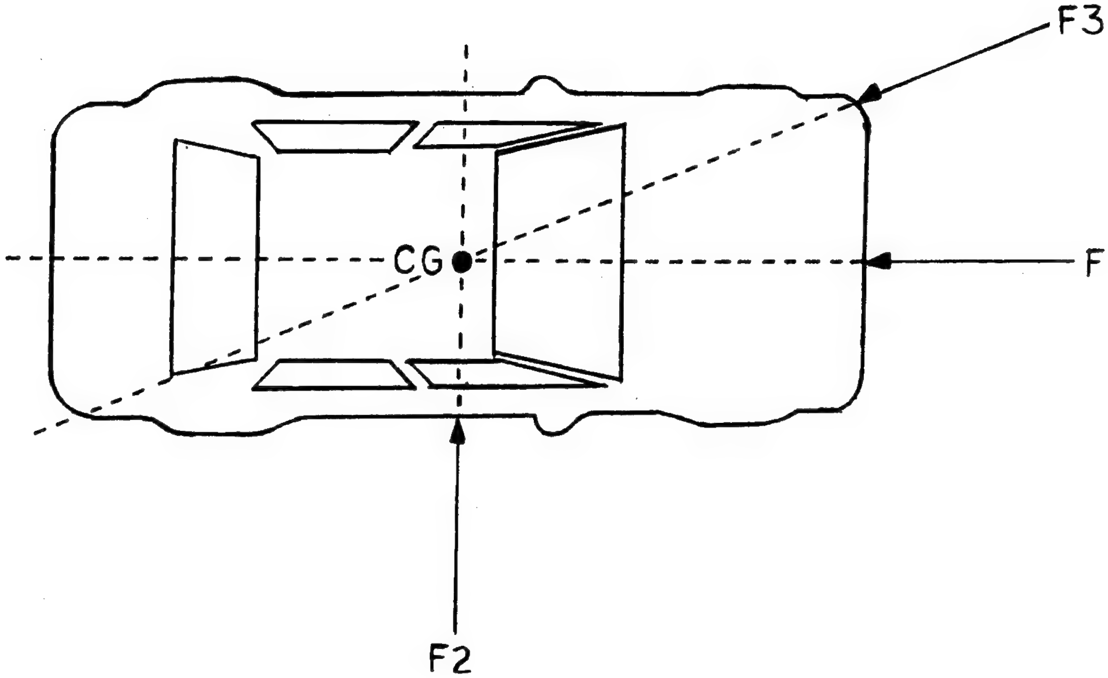
Center of Hydrodynamic Resistance

Figure 7-3



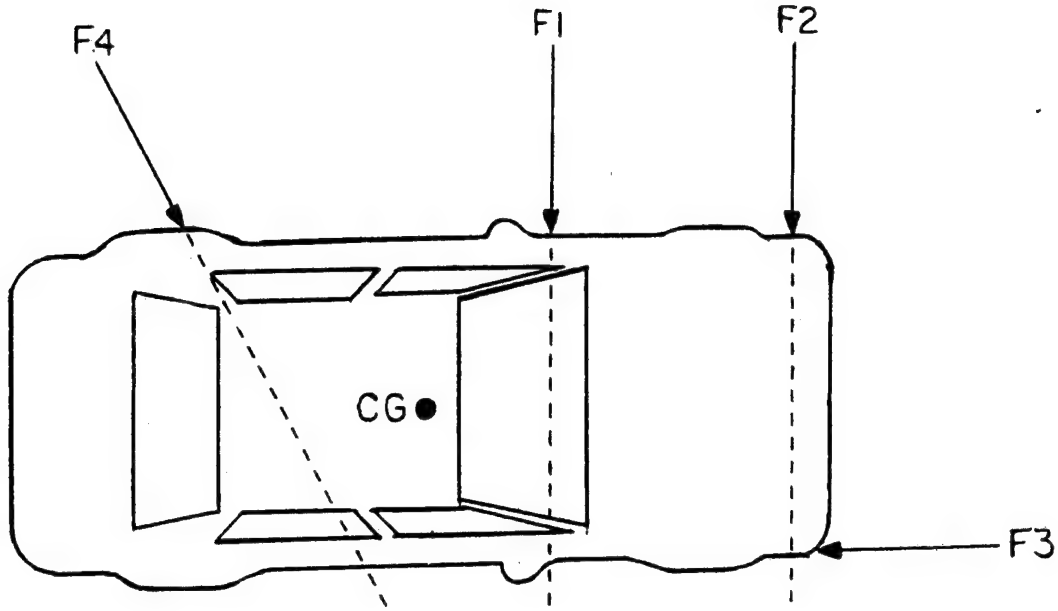
The Effect of CG and Impact Forces on Boat Rotation

Figure 7-4



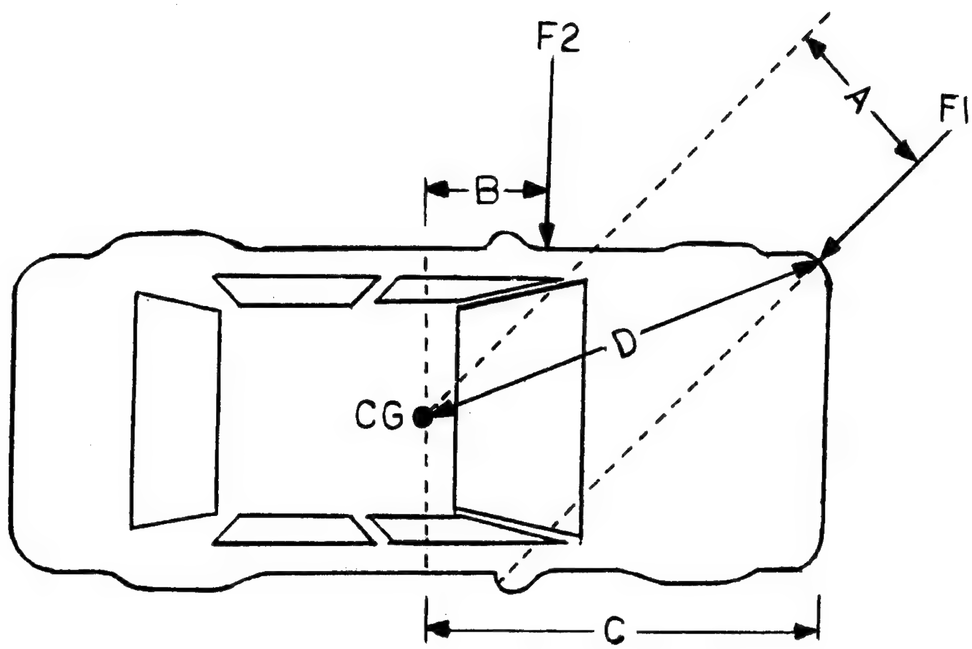
Centered Impact Forces

Figure 7-5



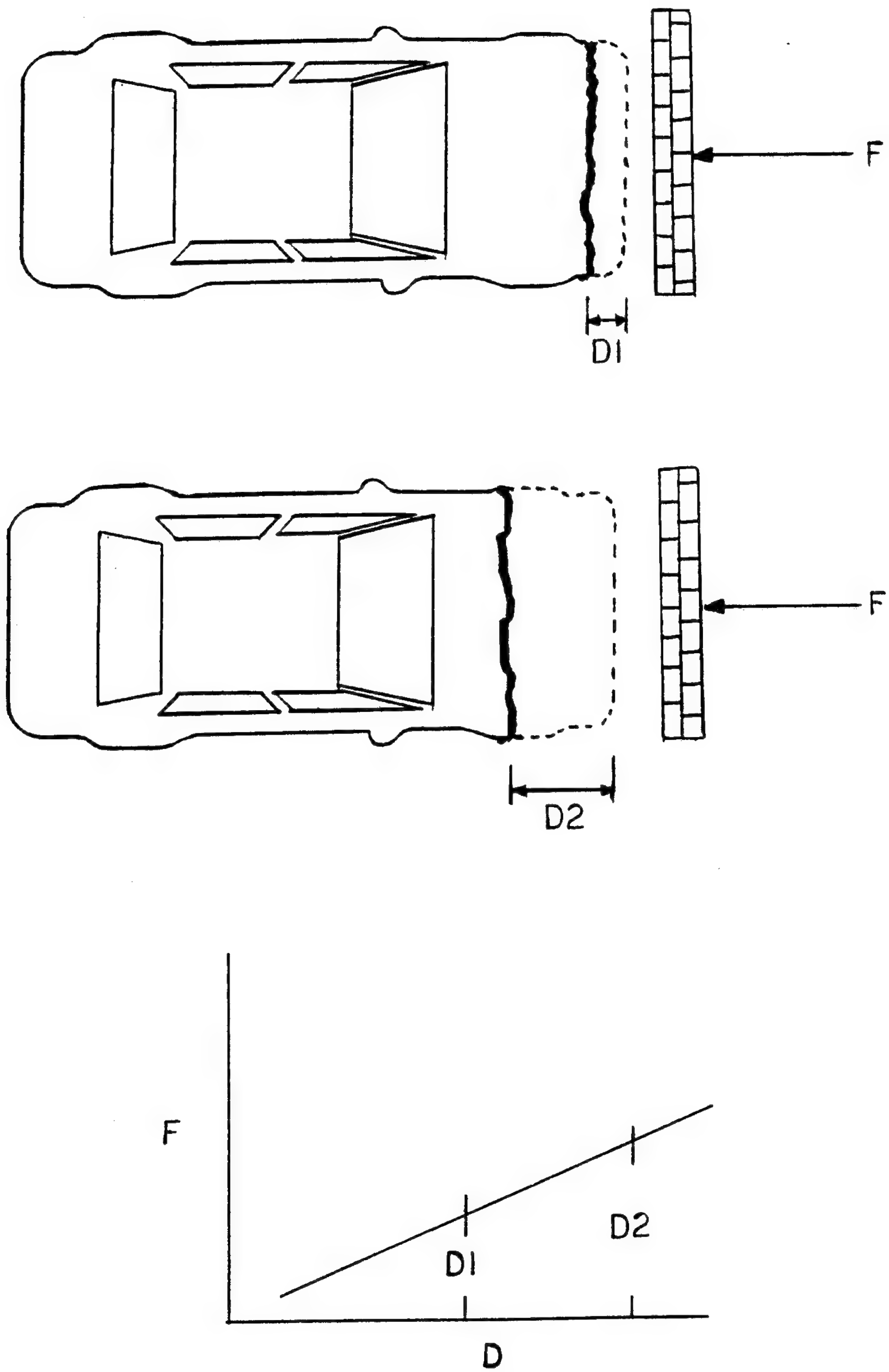
Eccentric Impact Forces

Figure 7-6



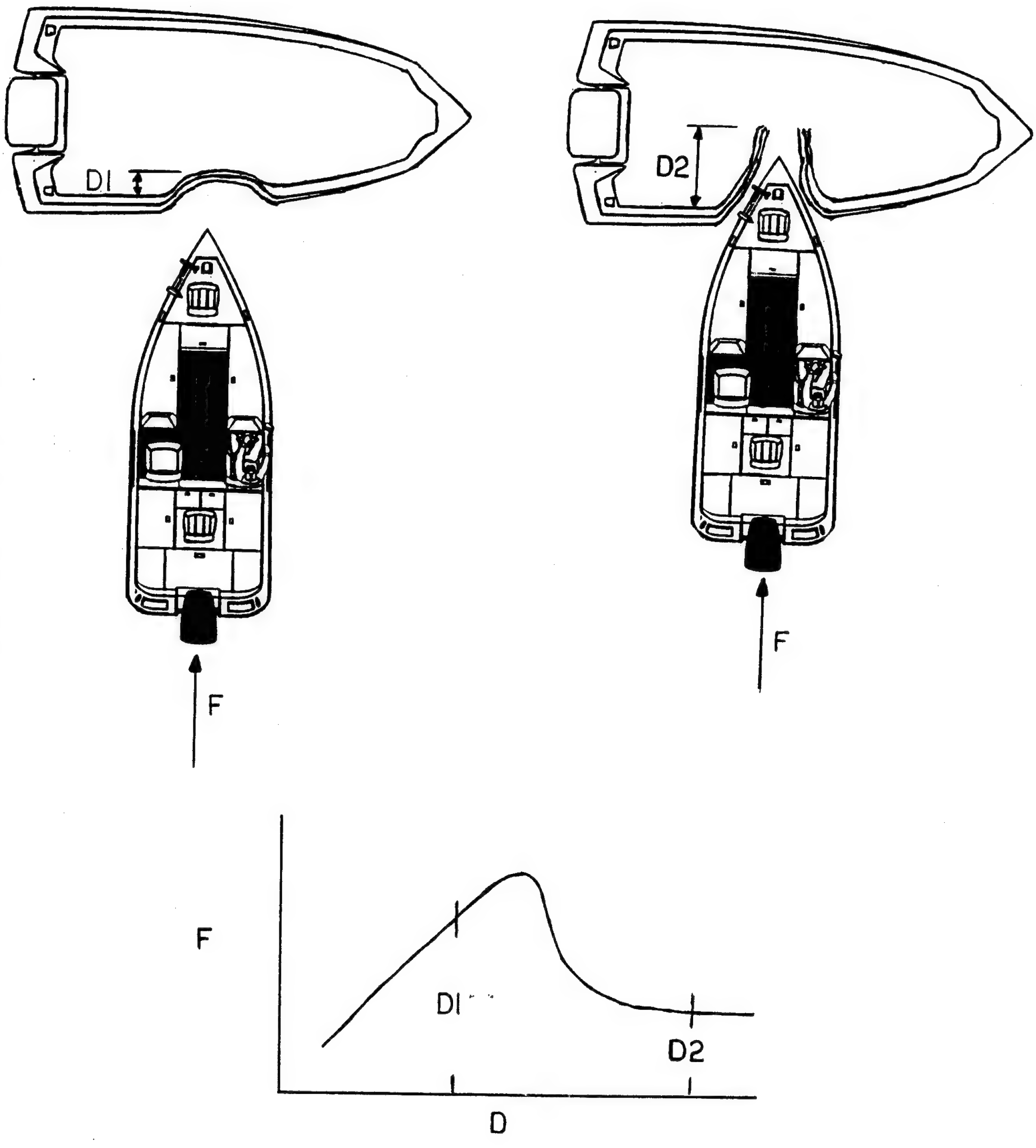
Calculating the Torque Exerted During an Eccentric Impact

Figure 7-7



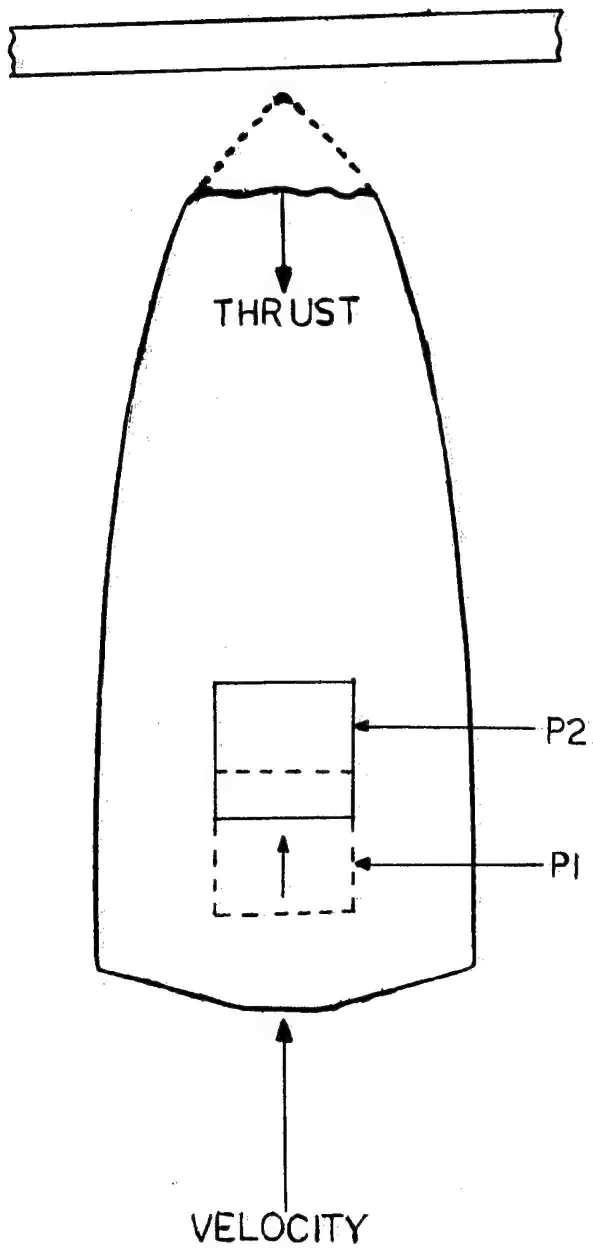
Relationship of Force to Penetration Distance for an Automobile

Figure 7-8



Relationship of Force to Penetration Distance During a Boat Collision

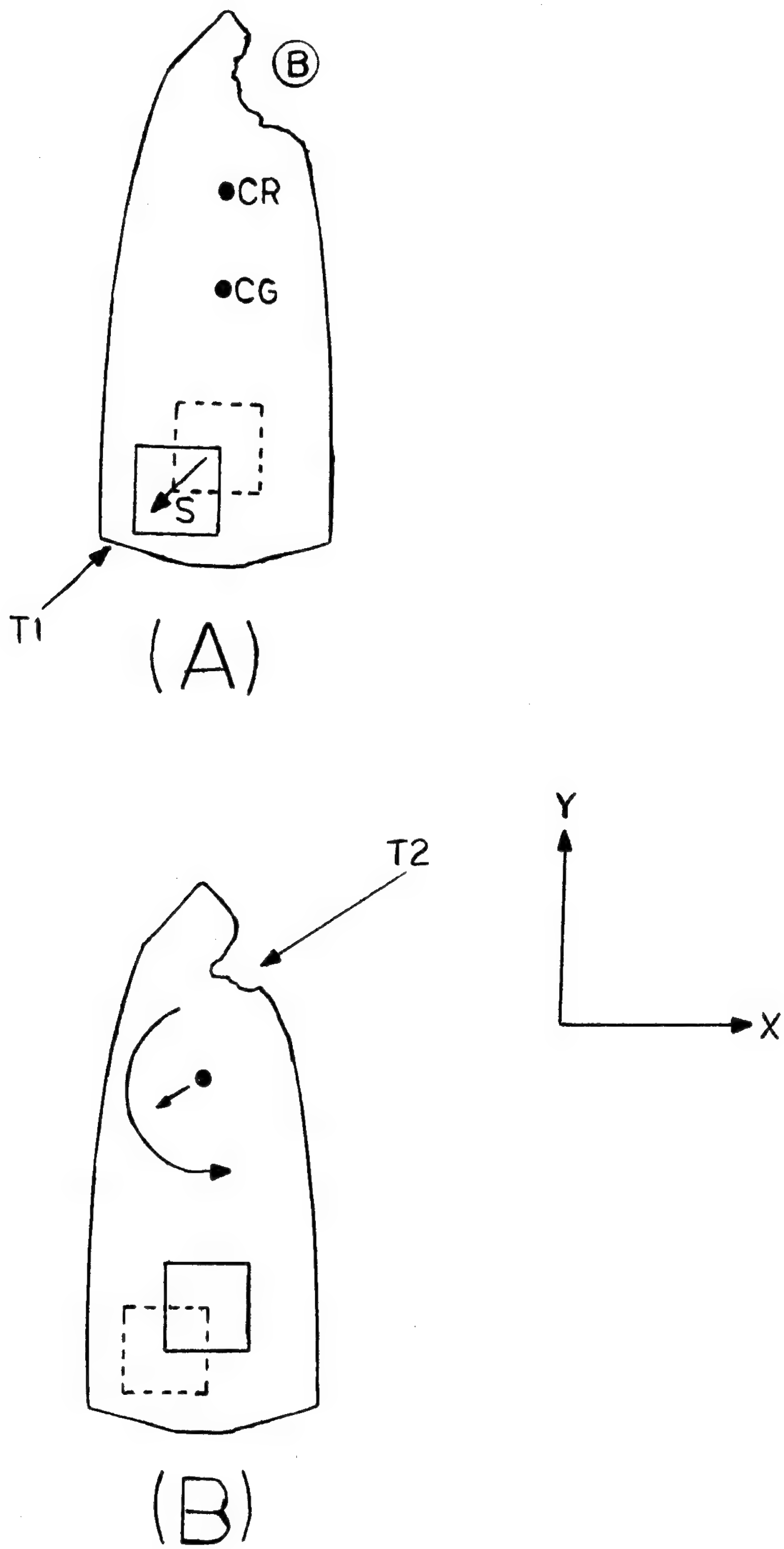
Figure 7-9



P1 = Pre-Accident Position
P2 = Post Accident Position

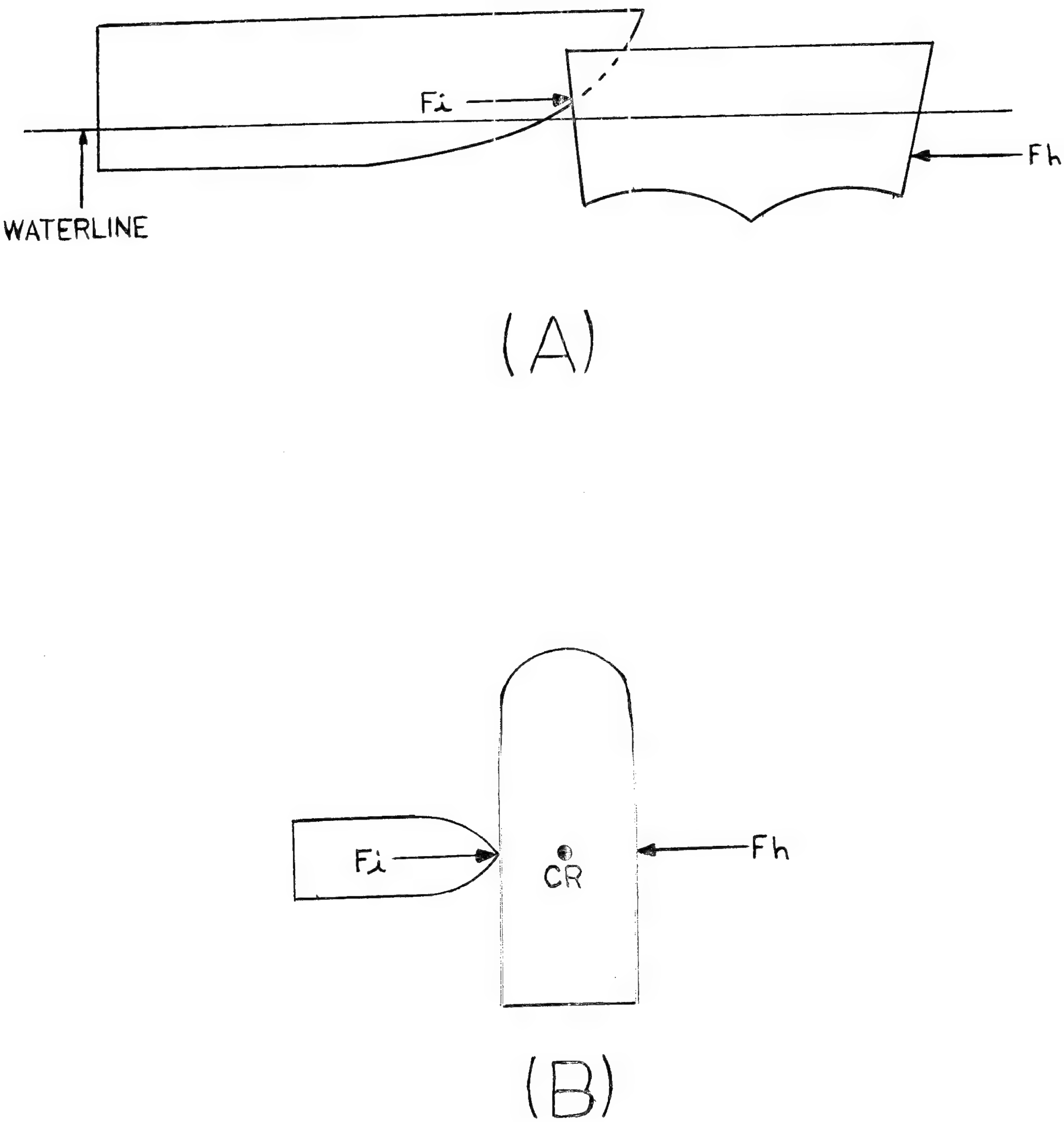
The Engine Cover Slides Forward During This Centered Impact

Figure 7-10



Unrestrained Objects Tend to Slide in the Direction Determined by the Local Acceleration Vector

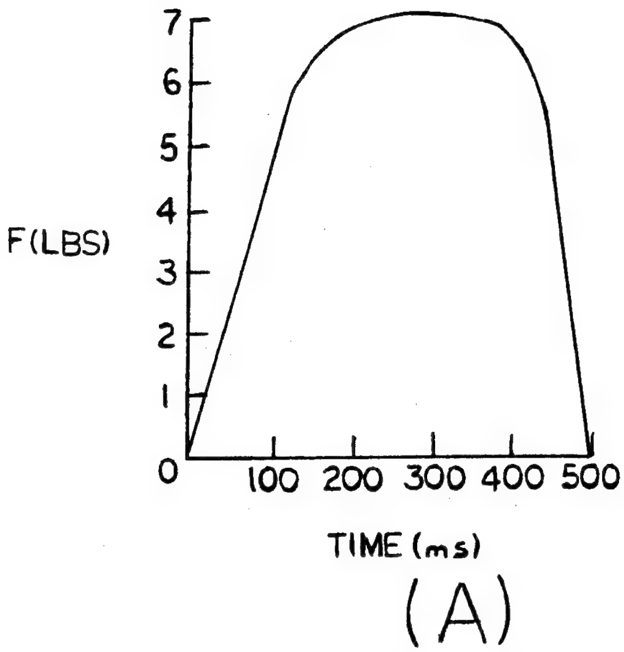
Figure 7-11



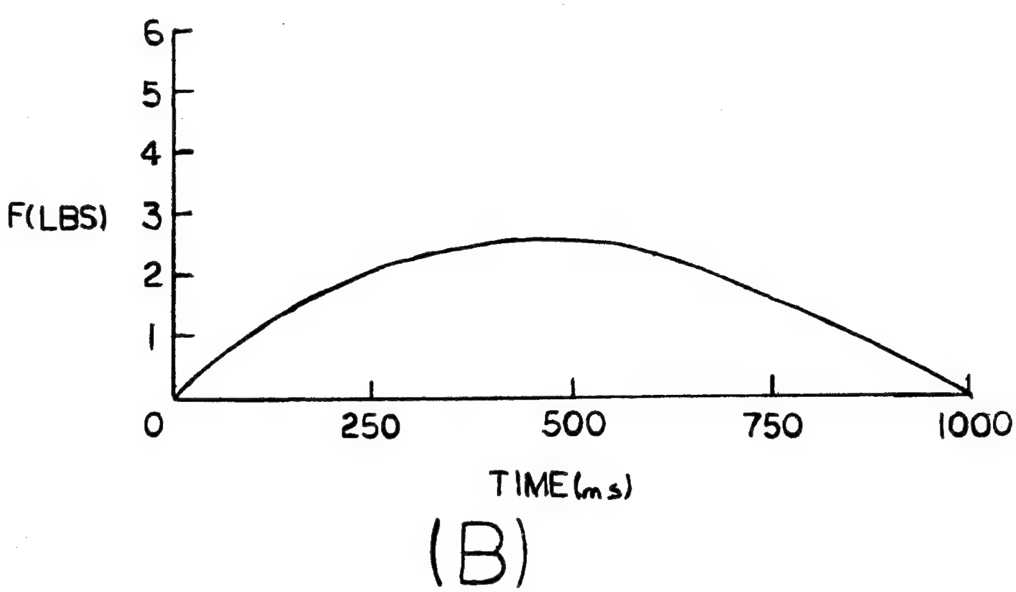
Fi = Impact Force
Fh = Hydrodynamic Resistance

Forces at Impact

Figure 7-12



Side Impact with Boat Having High Lateral Resistance and High Mass



Side Impact with Boat Having Low Lateral Resistance and Low Mass

Theoretical Force versus Time Curves

Figure 7-13

CHAPTER 8

AUTOMOBILE ACCIDENT RECONSTRUCTION TECHNIQUES AND HOW THEY RELATE TO BOAT COLLISION ANALYSIS

8.0 Introduction

Automobile accident reconstruction as a serious field of study has been around much longer than boat collision accident reconstruction. Much has been learned about automobile accidents. The purpose of this chapter is to show how concepts of automobile collision accident reconstruction relate to the study of boat collisions.

Cars have been running into each other almost as long as cars have been around, and accident reconstruction techniques have been evolving since at least the 1920s. The advances made in the last thirty years are of great significance. Even so, experts in automobile accident reconstruction are quick to point out that it is usually not an exact science. Initial speed estimates are more appropriately expressed in ranges of probable speeds than in mph carried out to three decimal places. Today, numerous books have been published on the subject of automobile collision accident reconstruction. Each year, additional papers are submitted to the Society of Automotive Engineers (SAE) on some aspect of this subject and added to the vast number already available. The field is well developed, and is advancing quite rapidly as of this writing. By contrast, published information specifically on boat collision accident reconstruction is virtually nonexistent.

Since automobile collision accident reconstruction is the closest developed field of study related to boat collisions, it is tempting to apply those concepts to boats. Many of the differences between auto and boat accidents were discussed in Chapter 6.

The purpose of this chapter is to focus on those areas of automobile accident reconstruction that have been developed that do apply or could be adapted to apply to the boating collision problem. Keep in mind that one focus of this research project was to develop collision accident reconstruction techniques based primarily on physical evidence.

A review of numerous texts on automobile accident reconstruction reveals that many of the exact same topics are covered in most of the better texts, although with a somewhat different approach. Each section title in this chapter is one of those common topics, and its applicability to boat collisions will be discussed.

8.1 Interviewing Witnesses

Interviewing witnesses is one area in the field of boating accident investigation upon which much has been taught and studied. The automobile accident reconstruction texts usually treat this subject well, also. Additionally, general witness interviewing is a common part of the training of most law enforcement officers. We will not be repeating the basics of witness interviewing in this report.

While virtually all that is generally taught about interviewing witnesses applies to boat collision accidents as well, it is useful to point out some of the different considerations. The primary difference is that often the boat operator or other occupants may be asked to make estimates of boat speed or to estimate distances on the water. For example, "How fast were you going, and how far away was the other boat when you first saw it?" are common questions.

Many boats do not come equipped with speedometers, making it difficult for the operator to know how fast he was going. In these cases, the boat may be equipped with a tachometer which the operator may or may not have read prior to the impact. When cruising, an operator may have a usual setting at which he will operate. The operator may then be able to provide an estimate of speed by saying that he was operating around 2800 RPM. It may then be possible to operate the boat after the accident at the same RPM to determine the boat's approximate speed.

Even if a boat has a speedometer, the operator may not have read it prior to the impact. The accuracy of the speedometer on a boat is generally unknown. Even if the operator read his speedometer just prior to impact, it is not safe to assume that the speedometer was accurate. Speedometers in the boating industry often indicate higher than the boat's actual speed.

Estimates of boat speed should first be obtained in general terms. The operator should be able to reliably tell if the boat was on plane, below planing speed, or somewhere in between. Once this has been established, the operator can the be asked for more precise estimates.

Estimating distances on the water is tricky even for the experienced eye. An operator's estimate of distances on the water should always be viewed with caution. Judging distances accurately on the water is a tricky task that the average boat operator has not mastered. This is especially true at night.

Boat operators are likely to be less familiar with the rules of the road than the typical automobile operator. An operator may make a statement about "making the right move" or about who had the right of way when giving a description of an accident. When this happens, the operator should be tactfully questioned to see if he really knows the rules of the road, or if he is merely trying to provide the right answers to the investigating officer.

The previous paragraph applies to navigation lights also. A boat operator may make a statement that another boat did not have proper lights, or that according to the lights displayed, the boat should have been traveling in a certain direction. When such statements are made, the operator should be tactfully questioned to determine if he really knows what lights are required. Once again, he may simply be trying to give what he believes are the right answers. This response is similar to the automobile operator who estimates his speed as "just below the speed limit" when in reality he had no idea what the speed limit was.

8.2 Examining Vehicles

Since the accounts of witnesses vary in degrees of accuracy and trustworthiness, it is desirable to find some unbiased method for determining what took place during an accident. One of the best records of those events in an automobile collision is the damage to the vehicle.

Analysis of a vehicle's damage can potentially be used to provide the following information:

1. the general directions of impact of one vehicle relative to the other, and the PDOF (principle direction of force)

2. the relative magnitude of the impact

3. the positions of the vehicles relative to each other during impact

4. estimates for the crush energy and hence the vehicle speed just prior to impact (for some collisions)

5. occupant motions

Can the above information be determined about a boat collision by examining the boat damage afterwards? Which of the techniques developed for automobiles to answer the above questions can be applied to boat collision analysis? Let's answer that question by considering the applicability of each one at a time.

1. Directions of Impact - General directions of impact may be determined in some cases by applying the same principles to boats as cars, but with caution. The way in which boats deform is much different than automobiles, however a general range of angles of impact can be determined. Interpretation of damage on boats can lead to incorrect estimates of impact angles if the effects of rotation are not taken into account.

2. Relative Magnitude of Impact - The relative magnitude of impact is difficult to quantify in boat collisions. Crash testing required for automobiles for safety reasons provides numerical specifics on automobiles for crush energy and deformation relationships. No such data exists for boats and the mechanics of the impact are much different.

   At this point in the field of boat collision accident reconstruction, it is not generally possible to determine an accurate impact speed of a striking vessel by examining the damage to a struck boat. In the future, it may be possible to estimate the minimum impact speed of a vessel based on physical damage. Even if it were possible, for certain impact geometries such as glancing blows and over-rides, this estimate will likely be much lower than the actual impact speed. This because an unknown amount of the kinetic energy of the striking vessel was retained as kinetic energy, and not converted into damage to the struck vessel.

   Glancing blows are good examples of accidents that can create a potentially high risk of injury, yet cause little visible damage. During an earlier experimental collision, a 16 foot outboard was struck on the bow by a larger boat traveling about 30 mph. The damage to the 16 foot boat was so minor that no one could have estimated the impacting boat's speed to be 30 mph based on damage alone. The 16 foot boat experienced rapid rotation during the impact which could have caused serious injuries to any occupants.

3. Relative Positions of Vehicles During Impact - Determining positions of boats relative to each other in a collision based on damage analysis employs many concepts from the automotive world. The concepts of damage matching, striation analysis and imprints are applicable to boats as well as cars. It is more difficult to leave an imprint in a fiberglass hull from a full impact than in the sheet metal skin of a car. Based on analysis of damage in field accidents, it

appears that before the stresses in fiberglass reach the level required to leave an imprint, the fiberglass typically shatters, breaks, or folds completely out of the way. The result is a damage pattern that may not resemble the component which struck it at all.

4. Vehicle Speed Based on Deformation - Estimates for crush energy and hence the speed involved are closely related to item two, and have similar problems. The data on the deformation of fiberglass structures during impact is not generally available to relate speed to damage during impact.

5. Occupant Motion Analysis - Many of the concepts used in automobiles to determine occupant motions applies to boats also. Steering wheels, dashboards, windshield frames, and other internal structures may leave signs that they were impacted by the occupant during the collision.

   High accelerations during an auto collision can cause an occupant to collide with such strong structures as doors and dashboards and leave a noticeable deformation. The impact of occupants with the hull interior near the sides of a boat has not yet been documented to cause similar deformations. This could be due, in part, to lower lateral accelerations experienced during boat collisions. Often the structures in the interior of a boat are of sufficient strength to withstand quite an impact from a human, without showing signs of deformation.

   Automotive texts are careful to explain the differences between contact and induced damage. These concepts apply to boats also, yet the actual forms of each will have differing characteristics.

   Standardized procedures have been developed by some texts, as well as by various law enforcement agencies for documenting damage to automobiles that goes well beyond completing a form. Standardization of procedures is a good idea and should be pursued for boat accidents as well. For autos, standardized procedures exist for damage diagrams, damage classification, documenting vehicle information, obtaining photos, examination of vehicle interior areas, instruments, lamps and other subjects. The investigator could learn much from the study of these subjects in automotive texts and subsequently apply many of the techniques to boats.

8.3 Tire Examination

Here's one that certainly has no relevance to boat collisions, right? In the literal sense that's true, however the subjects of friction, drag factor and tires usually go together in the automobile world. The subject of friction is of great importance to boat collisions. Boats slide over one another during an over-ride collision and during an impact with a boat dock or shoreline. The boating accident investigator is not going to be concerned with the details of tire examination, but the understanding of friction and its role in auto accidents can be helpful in the analysis of a boat collision.

8.4 Speed Estimates From Skidmarks

There is an old saying among boating accident investigators, "boats don't leave skidmarks." Admittedly, the idea of boats leaving skidmarks seems a little ridiculous at first. Can you picture a 19 foot ski boat slamming on breaks and coming to a screeching halt from 40 mph, laying down a trail of fiberglass across the calm lake? Not hardly, although some might say that this describes a grounding pretty well!

Estimating speed based on skidmarks employs concepts of work, energy, and friction (or drag factor). Boat accidents involving a boat which runs aground, or slides along a shoreline, dock or other surface out of the water are parallel concepts to estimating speed from automobile skidmarks. We will discuss more on the details of this technique later. For now, it is enough to realize the parallel between the two situations, and that a study of this subject in a good automobile collision accident manual would likely be helpful to a boating accident investigator.

8.5 Drag Factor and Friction Coefficient

When discussing the subjects of drag factor and friction coefficients as they relate to boats, it is critical to understand that these terms only apply to those situations where a boat is generally out of the water and sliding across a surface. These terms do not apply to a boat that is in the water. When a boat is in the water, we are concerned with the hydrodynamic resistance. Be careful here, some texts on boat design and hydrodynamics will refer to the resistance of the motion of a body through a fluid as the drag. This should not be confused with drag factor associated with automobiles as we discuss it in this section.

8.5.1 Dynamic Friction

Any basic physics text will likely have ample information on friction and friction coefficients. As a quick review, remember that friction in simple terms is the resistant force that develops when two surfaces in contact attempt to slide across each other. The friction force develops opposite of the direction of motion, or impending motion, and its magnitude is proportional to the contact forces (also called normal forces) between the two surfaces. Automobile collision accidents potentially involve at least three types of friction, static friction, dynamic friction, and rolling friction. Dynamic friction is the only one generally considered significant. In equation form, the definition of friction is

$$f = uN$$

This equation was also presented in Chapter 7, Section 15. Dynamic friction is the primary type of friction we will be studying related to boat collisions.

8.5.2 Drag Factor Explained

Automobile reconstructionists also concern themselves with drag factor. Automobiles typically have four tires that are in contact with the ground, and each one may be in a different state during an accident. A tire could be sliding, rolling, or slipping; therefore, the friction force generated by each tire as a vehicle slows could be different. The vehicle as a whole will only slow with one value of deceleration. This value is the drag factor. One practical view of the definition of drag factor is best understood by considering the following equation:

$$D = \frac{a}{g} \text{ or } a = gD$$

where

D = Drag Factor
a = acceleration or deceleration of the total vehicle
g = acceleration due to gravity

The drag factor (D) then is the deceleration or acceleration value of the total vehicle expressed as a fraction of the acceleration due to gravity (the gravitational constant).

As an example, let's assume the following conditions for a vehicle. Assume that the coefficient of friction between the tire and the roadway of a typical four-tired vehicle is 0.5, and the operator slams on the brakes. Assume also that only one wheel locks up, while the others are still rolling. The vehicle will

slow, but with a drag factor much less than 0.5. If all four tires had locked, then the drag factor and the coefficient of friction would be equal (0.5 in this case). In other words, the vehicle would have decelerated at a rate of 16.2 ft/sec squared.

Some automobile accident reconstruction texts use the following equation to help estimate the change in speed of a vehicle which leaves skidmarks:

$$V_i = \sqrt{V_e^2 - 2ad}$$

where

V_i = initial velocity going into the skid
V_e = the velocity of the vehicle at the end of the skid
a = the acceleration of the vehicle (a negative number for skidding)
d = the skid distance

This equation makes several important assumptions which have been found to be basically true for automobiles, but may or may not be true for boats. The equation assumes that the deceleration is constant throughout the skid. It also assumes that the coefficient of friction does not change for the length of the skid. This equation when combined with the definition of drag factor and friction may be useful in estimating boat speeds prior to grounding. The concept should be verified by testing before it is used in a reconstruction. Automobile texts offer further refinements on the equation to allow for crossing across different surfaces in the same skid and for skidding up or down a hill.

8.5.3 Drag Factor As It Relates To Boats

It is easy to understand where friction relates to boating accidents. But what does the drag factor have to do with boat accidents?

Coefficients of friction are parallel concepts for automobile tires and smooth bottomed boats, not taking into account the effects of a lower unit or a propeller. Drag factor is parallel to describing the deceleration of the total vehicle, whether it be an auto or a boat, including the effects of a propeller or lower unit. Interestingly enough, the drag factor for a boat may be markedly different than the coefficient of friction of the hull.

If we place a smoothed bottom boat hull on a boat ramp or wooden dock, we would find that it is possible to develop a set of friction coefficients for a variety of surfaces. It is likely that these values would be repeatable if all the variables were carefully controlled. Figure 8-1 shows a diagram of how the friction force acts on a smoothed bottom boat being pulled along a smooth hard surface. In this diagram, a boat of weight (W) is moving with a velocity (V) across a hard surface. The boat slows down as the friction force (f) acts on the boat hull. The normal force (N) supports the weight of the boat.

If the same tests were conducted on boats with their outdrives lowered, or on inboard boats with their propellers installed, a new problem is encountered with measuring friction, especially on non-uniform surfaces such as a sandy beach or a muddy shoreline. Figure 8-2 illustrates what can happen if a boat attempts to travel across the muddy shoreline. The lower unit, propeller, orother objects which protrude beneath the boat will likely be dragged through the mud, creating a noticeable rut which marking its path. The boat now slows due to a combination of friction (f), and drag of the lower unit through the mud. While there is a resistant force on the lower unit, it is not really a friction force. The force generated by the dragging the lower unit through the mud also creates a moment about the lower unit that causes an increase in the normal force. The result is the tendency to drive the forward parts of the hull deeper into the mud. This further complicates attempt to describe the motion of the boat using only friction equations.

8.5.4 Drag Factor or Friction - Which Term Applies?

Picture an I/O sliding across a muddy shoreline. Is the boat slowing due to friction or due to drag forces on the lower unit as it plows through the mud? For muddy or sandy surfaces, it is likely a combination of both. The boat hull is slowing due to friction, and due to the drag forces experienced by the lower unit. If the forces resistant to movement of the boat hull through the medium do not conform to the classic friction equation shown above in section 8.5.1, then the forces are not purely friction forces.

Attempting to relate friction coefficients to boat hulls sliding across soft, deformable surfaces such as muddy or sandy shorelines is a rather controversial task. Physics texts in their discussions on friction and the application of classic friction equations generally assume that the two surfaces being discussed are hard uniform surfaces. These equations were never intended to apply to boats sliding across soft sand and mud!

Some texts on automobile accident reconstruction warn against using coefficients of friction, and hence using skidmarks, or perhaps more appropriately tire ruts, to estimate speed on non-uniform surfaces. These surfaces might include gravel, packed dirt, sand, mud, snow, etc. The formulas for estimation of friction forces that oppose the objects movement may begin to fail us when the sliding object begins to dig ruts and push the dirt, mud, snow, etc. out of the way. For these situations, the resistant force may increase as a function of the distance slid, since to a certain degree, the material may build up in front of the sliding object in increasing amounts as the objects slides across and digs into the surface. Figure 8-3 shows an example of this. The car has locked up its rear wheels on a sandy road. The locked tire has dug a rut and material has built up in front of the tire. As a result, the car no longer stops due solely to friction forces. This type of action is difficult to predict or model in a repeatable manner. The car in Figure 8-3 is comparable to a situation where the coefficient of friction changes as a function of velocity. It should be noted that classic friction theory does not allow for the coefficient of friction to change as a function of velocity, which may occur with non-uniform surfaces.

For both autos and boats, the coefficient of friction between the hull and the surface which it contacts is not the only factor in determining the rate at which the total vehicle decelerates. Care must be taken during a boat collision accident analysis to note if you are considering the coefficient of friction or the drag factor. A boat relieved of the drag of its propeller and lower unit has the potential to slide much farther through or over a non-uniform surface than one with its propeller installed.
The practical implications of this subject for the accident investigator are that coefficients of friction are more likely to be repeatable and reliable values that can be determined by testing. Drag factors, as they apply to boats, may be difficult or virtually impossible to measure or duplicate in a repeatable manner for many surfaces. In other words, estimating speed based on friction is probably only repeatable if the boat runs up onto a hard uniform surface, such as a concrete boat ramp or wooden boat dock.

When a boat runs up onto a shoreline, the investigator must determine whether he is looking at a case of estimating a friction coefficient or if other forces were involved. As a rule of thumb, if the surface is soft enough so that the boat traveling over it deforms the surface, leaving ruts and deep gouges, then there is more involved than just determining a coefficient of friction. What is really needed is the drag factor, which may be nearly impossible to determine. The chances of accurately estimating the drag factor by testing in this case are not good. If the boat ran over a hard surface and no significant surface deformation occurred, then a coefficient of friction could likely be obtained that would be a reasonably good estimate and a repeatable value. The reason for performing such an analysis is to obtain the pre-impact speed of the boat.

To date, instrumented tests have not been conducted specifically to measure the coefficients of friction between hulls and various surfaces. Known values for various hull material and surface combinations can not be published at this time.

8.6 Vehicle Dynamics

Fortunately, in spite of all the obvious differences between automobiles and boats, both must react in accordance with the basic laws of physics. A good understanding of the fundamental applications of vehicle dynamics can be obtained by studying the methods of dynamic analysis applied to automobiles. While the actual forces and impact mechanisms are different for boats, the fundamental principles are the same.

The concepts of thrust direction, maximum engagement, rotation due to impact forces, and centered and non-centered impacts, are all concepts applied to automobile collision analysis that apply to boats as well. Many of these concepts are the basis for the material contained in Chapter 7 of this document.

8.7 Photography

In this section we will look at how the applications of this topic as developed for automobile accident investigation relate to boating accidents. Photography involves the art, science, and technique of taking good photographs. A good photographer will use proper equipment and knows what needs to be photographed.

8.7.1 Photography and Automobile Collisions

Photography remains one of the best methods to document the way things appear to the eye. No amount of maps or sketches can replace a few good photographs of the complex damage pattern on an automobile.

Photographs in automobile accidents primarily relate to two areas. The first is the information necessary to document the accident scene and the vehicle locations. Ideally, all relevant scene data is photographed. This would include skidmarks, debris patterns, fluid spills (such as coolant splatter) and any other objects that had relevance to the accident. The ultimate goal is to obtain sufficient data to accurately draw a scale map of the accident scene with all pertinent details in place.

The second area where photographs are critical is automobile damage. Careful photographs and measurements are often made to document vehicle damage. In some cases, this data can be used to develop a speed estimate from the crush data obtained from the vehicle. Photographs are also important on vehicles to show imprints, contact areas, and striation marks.

One important practice that has been implemented in automobile accident investigation is the recommendation that at least four standard photos should always be taken. Getting investigators in the habit of taking standard photos is beneficial since often the photos which are taken do not provide the necessary information for reconstruction.

8.7.2 Photography and Boat Collisions

The techniques developed for good photography that involve such subjects as proper lighting, lens selection, close-ups, and perspective apply no matter what the object being photographed. The big difference when the subject of boat collisions is addressed is what is important to photograph. Categorically, scene data in a boat accident become less important, and the damage to the boat becomes the first priority. The scene of a boating accident is usually not precisely known. It matters little for the water will obviously erase fairly quickly most signs of an accident. The boating accident investigator does not have the luxury of photographing the final rest position of vehicles, the impact points, skidmarks, and the like; therefore, all of the techniques of scene documentation used in automobile accidents are not as important. Exceptions are accidents which involve a fixed object such as a bridge piling, or a boat which runs up on shore.

Generally, the more important data are generally the documentation of the damage and deformation of the boats involved in the collision. It is important to document damage to the boats with as much precision as possible. Unlike autos, the reason has nothing to do with obtaining speed estimates from crush energy. At this stage in technology, these photos are primarily geared toward damage matching and possibly striation analysis. Good photos of the boat interior are of critical importance. Anything that shifts in the boat, whether it be permanent structures or loose objects, is a potential indication of the thrust direction and thus, impact angles.

A concept parallel to auto accident investigation is that of photographing the vehicles at the scene before they are moved, if possible. This helps to establish what damage was done as a result of the accident and what may have been altered by moving the vehicle. This is perhaps more important in boat accidents, because

the damaged boats are more fragile than their four wheeled counterparts. Large sections of a hull may literally be hanging by a few threads. It is critical, when possible, to photograph the damaged boat before moving it to another location.

Another difference in photography between autos and boats is due to the relatively flexible nature of fiberglass. The fiberglass will bend, break, and often snap back into its initial position with relatively little visible damage from the outside. Crawl inside, and all the wooden support structures in the vicinity will provide indications about the deformation which took place. Fortunately, when wood bends far enough that it breaks, it is usually obvious; and it is often possible to tell how far it bent. It may be necessary to remove headliners, carpet, and anything else that is between you and the outside layer of fiberglass to reveal the true nature of the damage.

Following the model of the automobile accident investigation, a series of standard photos have been suggested for boat collisions, as well as a checklist of items which should be considered. These procedures are covered in detail later in Chapter 10 as well as are the specifics of what should be photographed.

8.8 Photogrammetry

Photogrammetry follows from photography as a science of making accurate measurements from photographs. For auto accident investigation, the primary application has been to develop techniques for drawing accurate post accident scale maps. Some techniques allow an investigator to draw an accurate map even if at-scene measurements were not made. The use of perspective grids, stereoscopic photography, and other advanced techniques is useful in automobile accident investigations but probably has fewer applications to boat collisions.

A that a perspective grid could be useful in accidents involving a boat which runs up onto the shoreline, where a long distance needs to be documented only from a photograph.

Photogrammetry for boat collisions is of primary importance in assisting the investigator in preparing a scale drawing of the boat and its damage. New techniques had to be developed from scratch in this area since no formal procedures previously existed. The specific procedures developed are covered in Chapter 10.

8.9 Trips, Falls, and Vaults

It almost sounds like a series of automotive olympic sporting events. It is actually a classification of automobile accidents where basic physics can be easily applied. Before proceeding further, we will define each of these terms before you start envisioning a sports car in a pole vaulting event, launching itself over a high bar.

8.9.1 Definitions

Falls - In general terms, a fall occurs when a vehicle is traveling forward and is no longer in contact with the surface over which it is traveling. The category of falls in the automobile area is a general term that also includes jumps as well. It applies to most any accident where the vehicle is traveling forward, and for whatever reason becomes airborne, and returns soon thereafter to the surface. It may land higher or lower than the spot from which it was launched.

Flips - A flip is a special type of airborne accident, which occurs when a vehicle is sliding sideways and the resistance of the tires is sufficient to cause the vehicle to leave the surface and fly through the air. If a vehicle sliding sideways hits a curb, it is likely to trip.

Vaults - A vault is similar to a flip except that the vehicle flips end over end instead of side to side.

In all of the above cases, the vehicle becomes airborne. From basic physics, we know much about the motions of airborne objects. Their motion is described using particle trajectory equations, which means in simple terms, that we neglect the effects of friction, treat the object as a single particle and consider only the effects of the initial velocity (which includes both magnitude and direction) and gravity. Automobile accident reconstructionists have developed an entire class of equations for these types of automotive accidents that allow the estimation of a minimum speed from measurable scene data.

8.9.2 Trips, Falls and Vaults Applied to Boat Accidents

Trips, falls and vaults are perhaps the closest parallel in the automotive arena to boat collisions, because most other auto accident types are two dimensional and do not involve the vertical plane. Remember that many boat accidents, especially those involving an over-ride, result in some type of trajectory motion. The equations used in falls, flips, and vaults are special cases of trajectory motion equations which can be used to relate height and distance traveled to the takeoff speed of the vehicle.

While it is difficult to document precisely, many boat collisions will result in a boat being launched through the air, and landing a short distance away. If the boat becomes airborne, or if there is a change in the height of the CG, there is a minimum amount of kinetic energy required to perform that motion. Hence, the analysis of trips, falls and vaults is about finding the minimum velocity required to achieve that motion.

The principles behind the analysis of trips, falls and vaults are applicable to boat collisions. It is perhaps this class of accidents, more than any other, that inspired earlier attempts to calculate a minimum boat speed for some types of boat collision accidents. Many formulas for boat accidents had to be developed from scratch, starting with the general trajectory equations, since the inputs used in most automobile accidents were largely unknown for boat accidents.

As we shall see in later chapters, the primary problem with applying the trajectory equations to boat accidents is in documenting the height and distance of the CG traveled.

8.10 Occupant Motion

The study of occupant motion is closely related to the study of vehicle dynamics. It is the motion of the vehicle which determines the resulting motion of the occupants and any other loose objects in the vehicle as well. Fortunately, this topic has been well developed and gets considerable attention in many automobile accident reconstruction texts. It is also fortunate that the concepts developed here for automobiles are almost directly applicable to occupants in boats.

The reasons for conducting a study of the occupant motions for boats are nearly the same as for cars. While one of the primary issues in either situation is determining who was the operator, there are additional reasons for conducting an occupant motion analysis in boats. If the occupant motion relative to the vehicle can be documented, it can be used as a good indicator to help determine the motion of the vehicle struck. This information in turn is valuable in evaluating the thrust direction and possibly the impact angle of the striking vehicle. This analysis can be of critical importance in boats since little outside information may be available to document the motion of the boats involved.

Automobile accidents involving roll-overs are actually similar to some boat collisions involving glancing blows. For instance, Figure 8-4 shows how the velocity of the two occupants in an automobile can be different in a roll-over accident depending upon their position in the vehicle. The vehicle in Figure 8-4 is experiencing a flip. The vehicle has slid sideways into the curb at relatively high speed. Figure 8-5 shows a situation for boats that can potentially produce similar occupant motions. This situation can occur when a boat traveling at relatively high speeds only partially strikes a second boat. The first contact position

is off center of the bow and catches the curved portions of the bow just enough to act as a ramp on that side of the boat.

The result can be an increase in trim angle accompanied by an immediate and sudden roll of the boat. The driver seated in the position labeled number two is in great risk of being thrown from the boat, especially if he is seated on his seat back as many are prone to do. What actually happens is that the boat will tend to rotate as it reacts to the impact, while the driver's inertia will resist that motion. The boat may literally rotate out from under him, giving the appearance that the driver fell over the side during the impact. In both Figures 8-4 and 8-5, the assumption is made that the actual axis of rotation is close to the side of the vehicle in which occupant number one is seated. In both accidents, the velocity of occupant number two is greater than occupant number one since that person is on the outside of the roll. This occupant may be at greater risk of injury. It is important to note that the occupant motion analysis is based on the same principles whether it involves boats or automobiles.

8.11 Driver View Field Analysis

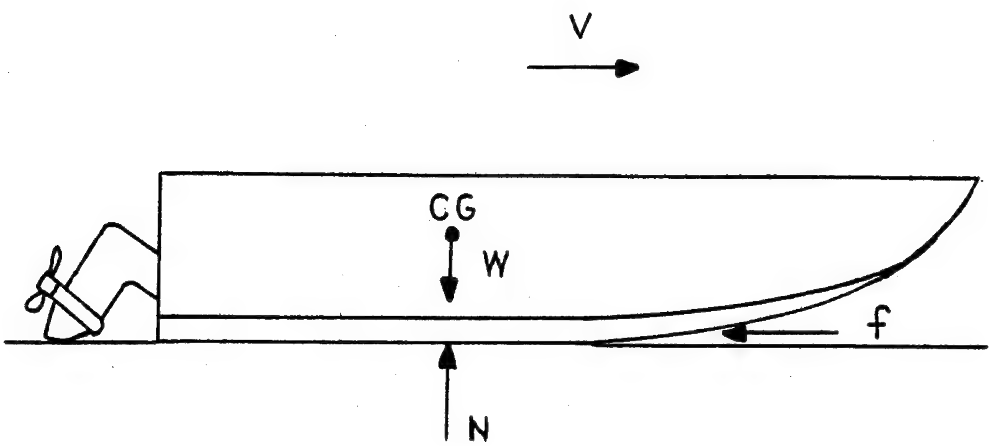
In an automobile collision, it is often necessary to determine when the operator of a vehicle was first able to see the second vehicle based purely on the geometry of a particular situation. These analyses are typically concerned with how obstructions outside of the vehicle such as buildings, hills, trees, bushes, and other objects affect the line of sight of the driver. Examples of boat accidents where these concepts apply include accidents which occur in small confined lakes, lakes with islands, accidents where other large boats may have blocked the vision of a driver and winding narrow rivers.

Occasionally the actual geometry of the vehicle will be the significant factor in restricting the field of view of the operator. In boat accidents, the field of view offered by the vessel is one of the most important considerations in the field of view analysis. In boats, one would tend to think that visibility is not a problem. After all, in a small open motorboat, there is no roof, no back window, and an apparent lack of anything significant to restrict visibility. This is not always the case. The geometry of the operator's boat may be the primary limiting factor in his field of vision. Large boats, especially cruisers with interior operator's stations, may offer a severely limited field of view for the operator. This must be taken into account when evaluating the actions of each operator and when trying to determine who saw whom first.

More so than in automobiles, the field of view for certain small boats can be severely affected by occupant locations. Bow-riders, which have seats in front of the operator position for passengers, have the potential to cause problems for the visibility of the operator when those seats are occupied while underway.

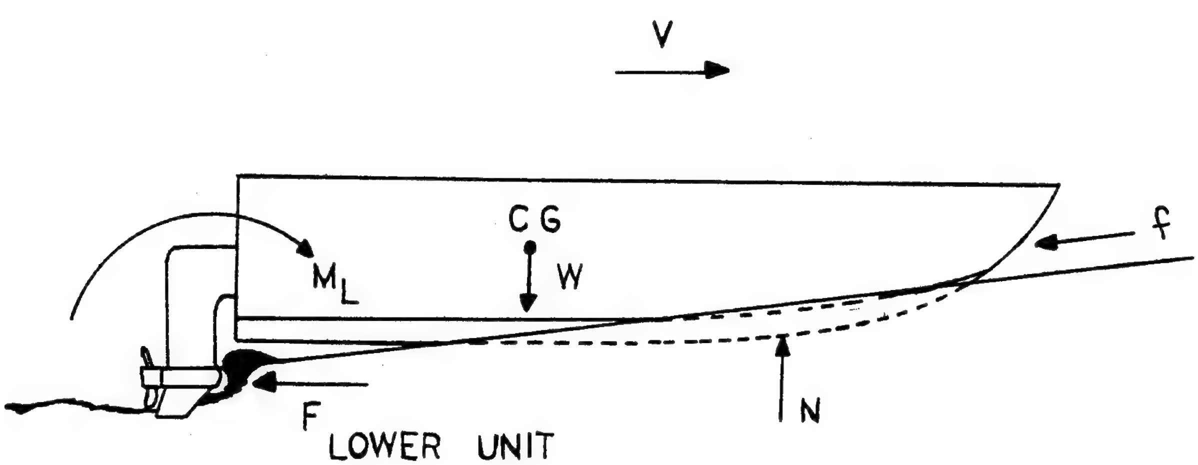
The last consideration is to remember that the field of view for the operator may be extremely different at night than during daylight. Small boat operators often complain about the glare from the all round white light mounted near the stern. This light may cause sufficient glare to prevent the operator from seeing other boats approaching at night from a wide range of angles.

The important difference between boats and autos is that the field of view analysis for autos generally deals with obstructions to vision which seem to occur outside the vehicle. For boat collisions, the vehicle is often the limiting factor.



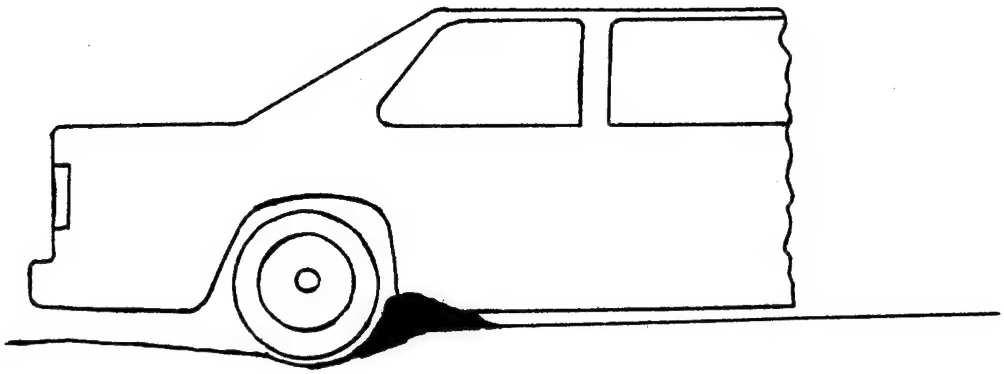
Boat Sliding Across a Hard Surface

Figure 8-1



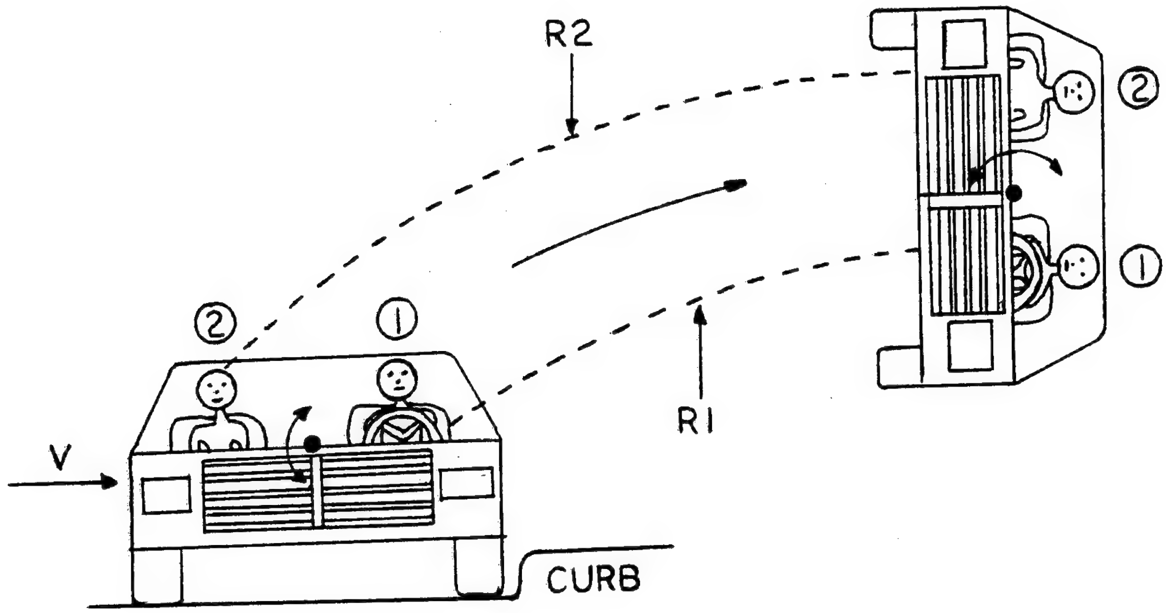
Boat Sliding Across a Sandy Shoreline. The Lower Unit has Dug into the Surface, Creating a Moment about the Lower Unit.

Figure 8-2



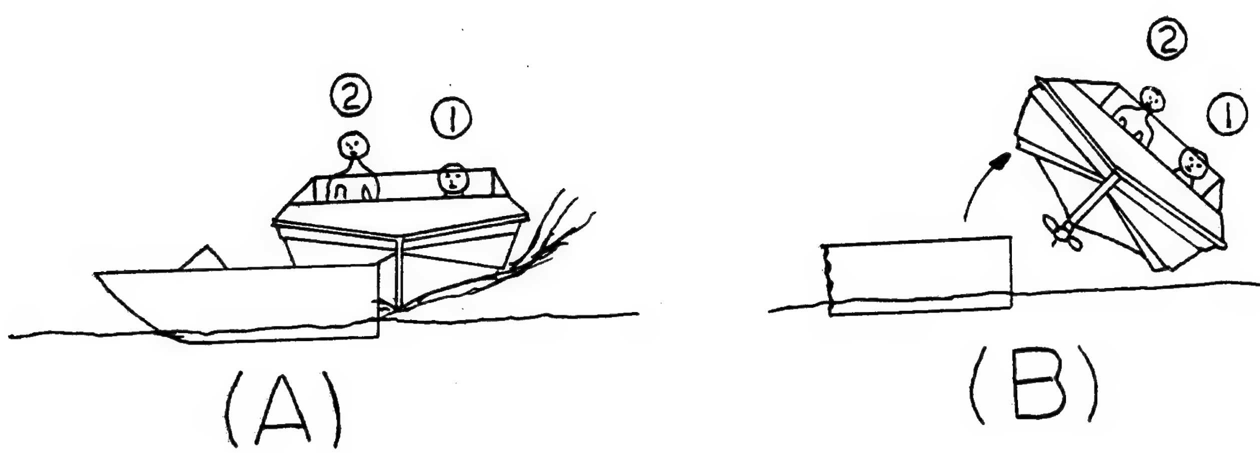
A Vehicle Which Locks its Brakes on a Soft Surface Causes the Tires to Dig Ruts, which Complicates Speed Estimates.

Figure 8-3



A Vehicle Experiencing a Flip. Occupant No. 2 experiences a Greater Roll Velocity than Occupant No. 1.

Figure 8-4



A Boat Experiencing a Glancing Blow Which Results in a Partial Over-Ride. Occupant No. 2 Experiences a Greater Roll Velocity than Occupant No. 1.

Figure 8-5

CHAPTER 9

DYNAMICS AND CLASSIFICATION OF VARIOUS ACCIDENT SCENARIOS

9.0 Introduction

The purpose of this chapter is to discuss in general terms the dynamics of various collision scenarios. We will also consider how to identify and classify those scenarios which are the most potentially dangerous.

So far in the study of small boat collisions, only small amounts of information have been gathered about how boats interact with each other on impact. Nonetheless, certain trends and tendencies have been identified for various collision scenarios. We will first discuss the scenarios and the variables which have an effect on the severity of the collision. Once we have identified the scenarios, we will discuss a possible method for classifying an accident based on the scenarios and variables identified. An accident classification system could provide a means to assist in identifying the most deadly scenarios in future studies. If some means of identifying and classifying the serious accident scenarios was developed, then this information could be coded on the accident report forms and included in future statistical studies. If for example, it was known that the most likely scenario to produce a fatality was when one boat struck a second stationary vessel and went over the top of the boat, then educators, boat manufacturers, legislators and enforcement personnel could concentrate on dealing with that particular accident type. Once we have discussed a possible method of classifying scenarios, we will look at the basic trends and dynamic characteristics for each one.

The information in this section is based primarily on various experimental collisions which have been captured on videotape. Most of these collisions were conducted by UL in the past. The field accidents studied in Chapter 13 and the statistical studies discussed in Chapter 4 also provided data for this chapter.

9.1 Developing an Accident Classification System

In this section, we will discuss the development of a possible classification system for collision accidents. The goal of this system is to concentrate on factors which directly determine the risk of death or injury to the occupants.

9.1.1 Classifying an Accident Scenario for CWAV

An accident classification system should provide a means of quickly identifying deadly accident scenarios and for determining the severity of the accident. The system proposed is based on identifying information either not found in the current accident reporting system or not consistently recorded by the accident investigators. Obviously, many factors go into an accident scenario which determine the cause. Many of those factors such as alcohol, weather, time of day, size of boat, etc. are already recorded on the accident report forms and are available for study. Factors such as time of day, air temperature, day of theweek and weather do not directly determine the potential risk of death or injury, and seldom is any single one of these items the direct cause. This information is useful in identifying common factors but does not directly determine the risk of injury to an occupant in an accident.

Thus, the system proposed is based on physical factors that directly affect the likelihood of death or injury based on physical properties of that particular collision scenario. Factors such as speed, boat structure, angle of impact, occupant location, and even the size of the boat have a direct effect on the potential risk to the occupants during a collision. One reason for concentrating on the physical parameters is that it may provide information that could someday be beneficial to designers and manufacturers of boats and components.

The USCG breaks collisions down into three types, Collisions With Another Vessel (CWAV), Collisions With a Fixed Object (CWFXO), and Collisions With a Floating Object (CWFLO). CWAV accidents can be further broken down into numerous subcategories. Doing so helps us discuss specific characteristics of each category of collision. CWAV accidents can be classified into major divisions of accident types by boat interaction, boat maneuvers and relative boat size. Specific scenarios will be discussed within each of these major divisions. An outline of the accident classifications discussed in this chapter is listed below:

I. Collisions With Another Vessel:

A. Classified by Boat Interaction -- Horizontal Plane
   1. Side impact
   2. Head on
   3. Stern impact
   4. Glancing blows
   5. Other

B. Classified by Boat Interaction -- Vertical Plane-
   1. Penetrations
   2. Combination of penetration and over-ride)
   3. Over-rides
   4. Contact only, no penetration

C. Classified by Boat Maneuvers
1. Both boats moving
2. Bullet boat moving, target boat stationary

D. Relative Boat Size
1. Large boat strikes smaller boat
2. Both boats approximately the same size
3. Small boat strikes larger boat

II. Collisions With Fixed Objects

A. Classified by Rigidity of Object Struck-
1. Rigid
2. Flexible or movable

B. Classified by Object Location in Relation to Waterline-
1. Underwater
2. Above water object

C. Classified by Boat Speed
1. On plane
2. Less than planing speed

III. Collisions With Floating Objects

This outline could also form the basis of an accident severity classification program. Over time, studies and statistics may provide additional information which helps to identify those scenarios which are the most dangerous. This data could be used to help boat manufacturers, enforcement personnel and educators to improve boating safety. The above information is organized by collision type (CWAV, CWFXO, CWFLO), classification and category. The CWAV type has four classifications with several categories in each classification. For any accident type, at least one category from each classification could be used to describe that accident. The specific category listed under each classification is in approximate order from most to least severe. This information could be used to help identify especially hazardous scenarios and their frequency, especially for CWAV accidents.

Consider the following example. A 24 foot cruiser traveling at 25 mph struck a 16 foot fishing boat that was sitting still in a cove.

The cruiser struck the fishing boat at nearly a 90 degree angle and rode completely over the boat. Using the system above, we could assign an Accident Severity Code to this scenario as follows:

Accident Severity Code: Type I, A1, B3, C2, D1.

The Accident Severity Code for this accident explains that this was a side impact involving an over-ride with only one boat moving, and that the large boat struck the smaller boat. Since the categories within each classification are arranged from most to least severe, we can add the numerical portion of the specific categories from each classification to develop a rough estimate of the total severity of the accident. We will call this value the Accident Severity Index (ASI). The ASI consists of three values. The first value is the total of the numerical portion of the specific categories from each classification. The second and third values are the range of values for the most severe accident to the least severe accident which exists for that accident type. For our example, seven is the total of the numerical portions of A1, B3, C2, and D1 (1+3+2+1). Four is the least value that the ASI could have and represents the most severe accident. Fourteen is the maximum value that the ASI could have, and it represents the least severe accident. The ASI for the example in the previous paragraph would be written as follows:

Accident Severity Index: 7, 4..14

In summary, for CWAV accidents, the possible values for the ASI range from 4 to 14, with the former value being the most severe accident.

The Accident Severity Code developed for the first example would apply to a particular accident, and would be the same for both boats when more than one vessel is involved.

9.1.2 Including Data on Injuries and Death for CWAV

What constitutes a severe accident? The severity code should relate to the potential of death, injury, and property damage. In order to know if our system is valid, we must relate the scenario code recorded to the number of deaths and injuries. This is partly a function of the number of people on board each vessel. Since property damage is of less importance, and involves extremely subjective judgments, we will not attempt to include this parameter in our classification system.

Since the most important goal of this research is to ultimately save lives, we must be able to easily obtain information regarding the number of fatalities and injuries which occur on each vessel. This in itself is not enough. How a person dies in an accident is of crucial importance. It is vital to know if a person died from injuries or from drowning. It is also important to know if the person drowned while wearing a PFD.

The goal is to develop a system that can be incorporated into accident report forms that investigators can easily complete, and still provide enough information to be useful in an analysis. The information needed for our classification system can be broken down into essential information, and desired information.

The essential information must include the following information for each vessel: number of fatalities, number of injuries, and number of persons on board. We could refer to this as an Occupant Summary Code (OSC). The reason for developing names and acronyms is to facilitate forms development for this information. For any CWAV accident, there will be two OSC values recorded, OSC1 and OSC2. In other words, there should be one code for each vessel. This information is the minimum required to assess the severity of the collision in terms of its effect on the occupants. The OSC can be used to provide a quick summary of the severity of the collision in terms of the number of people injured or killed compared to the number on board. As an example, the OSC for the struck boat, which should always be labeled vessel 2, or the target boat, would have an OSC2 code. Let's assume that on the target vessel that 15 people were on board, five were injured, and two were killed. The OSC code would appear as follows:

OSC2: 2-5-15

The use of dashes is recommended instead of a backslash "/" character which can easily be mistaken for the numeral one when written by hand.

The OSC only provides enough information to arouse our curiosity. It does not provide enough information to properly direct a response. Additional information regarding how the death of the occupants occurred and the severity of any injuries is needed. It is also needed in a simple format that will not be an unreasonable burden on the investigator.

Fatalities can be broken down into two distinct categories, drownings and injuries. The person either was thrown out and drowned, or died from injuries. Admittedly, there are those cases where both occur and it is not possible to tell which was the cause of death. Usually, death can be attributed primarily to one or the other. The second item needed is to determine if the person was thrown out of the boat on impact or if he stayed in the boat. Based on an analysis done in Chapter 4, this factor is of critical importance in determining the risk of injury. The third piece of information needed is to determine if the person drowned while wearing a PFD. Based on an analysis conducted in Chapter 4, a surprisingly high number of deaths in collisions may be occurring simply due to people not wearing PFDs. The answer to the questions discussed in this paragraph could be put into a simplified code form in the following format:

Occupant Fatality Code (OFC):

Death By:	Thrown OB:	PFD Worn?
1. Injuries	1. yes	1. yes
2. Drowning	2. no	2. no
3. Unknown	3. unknown	3.unknown

The Occupant Fatality Code (OFC) should be recorded for each fatality on a boat. As an example, the code for a person who died from injuries, was thrown overboard and was wearing a PFD would appear as:

OFC1: 1-1-1 OR I-y-y

The numeral one following the OFC designation indicates that this is the OFC for occupant number one in the vessel. All occupants should be given a unique number to help avoid confusing the data of one person with another.

The last issue of vital importance deals with the injured. It is important to distinguish between severe injuries and minor cuts and bruises. Many accident forms already have a place to note if injuries required treatment beyond first aid. This is a logical place to draw the line between severe and non-severe injuries. We would also like to know for each injured person on a boat if he was thrown overboard and if he was wearing a PFD. Obtaining additional information on the injured would fill a gigantic gap in the current data gathering process. Evaluation of many current accident report forms shows that often injuries noted by an operator are left unrecorded on the investigating officer's accident form. We now have the ingredients for an Occupant Injury Code (OIC) which should be recorded for each injured person on a boat. The OIC should be in the following format:

Occupant Injury Code (OIC):

Injured Beyond First Aid?	Thrown Overboard?	PFD Worn?
1. yes	1. yes	1. yes
2. no	2. no	2. no
3. unknown	3. unknown	3. unknown

An example of the OIC for an injured person requiring treatment beyond first aid, who was thrown overboard and was not wearing a PFD would appear as follows:

OIC1: 1-1-2

Both the OICs and OFCs should be followed by a number whenever more than one occupant is involved. The occupants should be uniquely numbered, and if a pre-accident seating diagram is provided, the numbers should correspond to the seating positions.

The particulars of each category (i.e., how much bigger does one boat have to be than the other before we classify an accident as one boat being larger than another?) will be elaborated on in paragraphs 9.3 and beyond in this chapter.

What is the benefit of an accident classification system and how would it be used? Such a system provides information concerning the basic scenario of that accident which could be quickly referenced and tabulated on accident reports on a national level.

The accident codes would help to identify the most common scenarios. If all of the accident codes described in this section were implemented, then better data would be available on which to make recommendations which would benefit boating safety.

9.1.3 Classifying Collisions With a Fixed Object (CWFXO)

The classification system discussed for CWAV could be easily carried over into the CWFXO accidents. The number of scenarios is greatly reduced, so the Accident Severity Code (ASC) for a CWFXO will be relatively simple to determine. Because there are fewer classifications and categories, the Accident Severity Index (ASI) values will be lower than for CWAV accidents. The ASI for CWFXO objects will range from only 3 to 6. As an example, the ASC and ASI for the collision of a 17 foot ski boat with a bridge piling at 40 mph would be written as follows:

ASC: Type II, A1, B2, C1
ASI: 4, 3..6

This accident type requires the investigator to make a judgement regarding the boat's speed. While the judgement is subjective, hopefully boats that were travelling below planing speed will be identified. For boats which clearly do not plane, such as kayaks, canoes, rafts, etc., it would be appropriate to substitute 20 mph as the planing speed threshold. Thus, non-planing boats such as these will virtually always receive an ASC that shows a speed below a planing speed. The categories developed for injury and death of occupants discussed for CWAV can be used directly for CWFXO accidents.

9.1.4 Collisions With Floating Objects

Accidents classified in this category involving fatalities are rather infrequent. The object struck is generally not seen in these accidents, which makes it hard to confirm that an actual floating object was struck. Refer to the analysis of CWFLO in Chapter 4 for additional information. Since so little data is available on these accident types, and the objects struck, it was not deemed possible or beneficial at this point to develop an Accident Severity Code for this type of accident. Keeping consistency with the other accident types, it would simply have a code as follows:

ASC: Type III.

There is no ASI for Type III accidents.

The OFC and OIC for fatalities and injuries will apply here in the same fashion as discussed for CWAV accidents.

9.2 Dynamics of Various Scenarios

This section is not designed to provide numbers, formulas, or sophisticated tools to aid in accident reconstruction. Instead it should provide something much better.. understanding. Section 9.1.1 outlined various classifications of accidents based on three critical factors. These were Boat Interaction, Boat Maneuvers, and Relative Boat Size. We will discuss the various trends and tendencies when each of the scenarios is considered independently of other factors. These are not absolutes, and exceptions will abound. Nonetheless, it is often useful to understand the general tendencies that occur when each of these factors are considered independently. What happens will depend on the speed of the boats at impact. Since low speed collisions below 10 mph are not as likely to cause death or serious injury to the occupants, we will limit our discussion to impact speeds of significance. It is also important to note that this discussion primarily applies to collisions where the struck boat is stationary. Many of the trends discussed may also be present in a collision where both boats are moving, however no data is available from any experimental collisions in the latter scenario for study. Remember that this discussion applies primarily to fiberglass motorboats, from 16 to approximately 26 feet in size.

9.2.1 CWAV: Boat Interaction, Horizontal Plane

Boat interaction in the horizontal plane is a rough way of describing the approximate angle of impact. More precisely, we are interested in how a collision progresses depending upon the point on the struck vessel which is contacted. The structural response of the bullet boat is not discussed here, because in most CWAV accidents, the bullet boat suffers relatively little structural damage.

A1. Side Impact- Simple Hull Side, No Cabin Structure

The side of an open motorboat is generally one of the weakest parts of the overall boat structure. First we will consider the factors involved in a simple 90 degree impact with an open motorboat with no other structures involved. By no other structures, we mean that the motor well, or console, was not in the path of the bullet boat. For this scenario, several key variables determine what happens in a side impact collision. These variables have been identified as:

a. the stiffness of the hull side
b. height of the gunwale at the impact point

c. the height and shape of the bow of the bullet boat
d. the resistance to vertical penetration offered by the hull side
e. the brittleness of the fiberglass

Let's discuss the sequence of events of a typical 90 degree side impact. When the bow makes initial contact, the side may flex along the top of the gunwale for a considerable distance. Low speed impacts have seen hull sides deflect for six inches or more and then fully return to their original shape. The hull side will deflect, with the greatest deflections occurring along the top of the side wall at the gunwale. The hull side will continue to deflect laterally until the stress at the contact points (usually the bow) with the striking boat cause the fiberglass to separate along a roughly vertical line that is in contact with the contact points of the striking boat. What happens after that varies depending on the particulars of the structure.

During a side impact, the target boat, as a whole, may remain in its pre-impact position until the bullet boat has penetrated a significant distance. This significant distance varies, but it may be until the bow of the bullet boat has nearly reached the gunwale on the opposite side of the target boat. At this point, several things are happening. First, the weight of the bullet boat is now beginning to be transferred to the target boat. Second, the target boat is settling lower in the water, or beginning to roll toward the bullet boat, or both. These two factors begin to work together to help the bullet boat ride over the far gunwale. Experimental collisions have shown that T-bone impacts typically involve penetration through the near hull side, and may result in little or no damage to the far side of the target boat.

In a typical T-bone impact, with a stationary target boat, the bullet boat penetrates through the hull side, dragging the lower unit through that same area. Experiments have shown that a side impact at 90 degrees will typically involve penetration of the struck hull side and an over-ride of the far hull side, at least for a collision between two small open fiberglass motorboats. During these collisions, the bullet boat may go airborne and travel for some distance before re-entering the water. Boats with low pitch moments of inertia have the tendency to achieve a high pitch rate during the impact process. Figure 9-1 shows how a 19 foot boat that achieves a 30 degree pitch angle during impact may experience only a 3 foot change in CG height, but a 9.5 foot change in height at the bow. This diagram is similar to the attitudes of some outboard boats used in earlier experimental collisions. The bow of a boat can rise high into the air during a collision, providing the false impression that the entire boat attained a great height. It is the change in CG height that is important when estimating boat speeds.

A2. Head-On Impacts

So far, we have little data on head on impacts. Early speculation held that if two boats met head on, that they would glance off of each other because of the shape of the bow. An experimental collision involving a near head on impact of a bullet boat with a stationary target boat showed that inertia prevailed. The bullet boat rode completely over the top of the target boat. The heavier the boats involved, the greater is the tendency to continue in the pre-impact heading. To date, the resulting damage from a known head on impact with both boats moving has not been recorded. It is unlikely however, based on the information discussed here, that the boats will simply glance off of each other.

A3. Stern Impact

The stern of a boat is extremely strong, especially where the hull sides meet the transom. The stern area of an outboard appears to be even more resistant to damage than that of an I/O. This is because the transom of an outboard boat must support the weight and stresses imposed by the propulsion machinery all on the vertical stern plate. If the impact occurs from dead astern, and an over-ride occurs, the propeller and lower unit are likely to travel right through the center of the boat, creating a serious risk of injury to the occupants. A bullet boat which strikes a stationary outboard powered boat in the stern may respond differently than one which strikes an I/O.

When a bullet boat strikes an outboard powered target boat from dead astern, it will most likely make contact with the outboard motor. Unless the impact is directly centered and aligned with the outboard motor, the result is that a roll moment will be imparted to the bullet boat. This roll moment can result in the bullet boat re-entering the water on its side. If this occurs, greater stresses, both to the bullet boat and to the occupants, may result. The risk of throwing the occupants from the bullet boat also increases. When analyzing the damage of such an accident, the markings of the outboard motor cowling are usually distinctive on the bottom of the bullet boat.

If this same impact occurs on an I/O, the bullet boat may retain a relatively level roll attitude. The transom height of many I/Os is well below the bow of the bullet boat. The geometry of this situation encourages an over-ride to occur.

4A. Glancing Blows

Glancing blows generally result in partial over-rides and little or no penetration. When a bullet boat strikes a stationary target boat, the resulting motion of the target boat is partly dependent upon the impact point. Figure 9-2 shows two extreme conditions. In Figure 9-2a, the bullet boat strikes the outboard

near the stern. The moment about the CG is relatively small, and the resulting rotation of the target boat may be relatively slight. If the impact point is moved further forward, as shown in Figure 9-2b, the resulting rotation can be severe. Experiments have indicated that the rotation could be of sufficient severity to throw a person from the boat or cause injury from secondary impacts if they remain in the boat. These accidents can be misleading to accident investigators because the resulting physical damage on both boats may be relatively slight. This phenomenon was discussed in detail in Chapter 7.

It is true in virtually all accidents that the center of lateral resistance (CLR) and center of rotation (CR) change moment by moment. It is especially important to be aware of this phenomenon in glancing blows as shown in Figure 9-2.

In Figure 9-3a, we see that the impact force is directed at the bow (coming directly out of the page). The boat is still in a level trim position, with the CG and CLR still in the pre-impact position. If the impact force continues to progress, rapid yaw rates may be experienced by the target boat. Figure 9-3b shows that the bullet boat has begun to ride over and press down the bow of the target boat. This forces the CLR to move forward. As a result, the moment of the impact force about the CR decreases, and the increased submerged area forward provides additional resistance to rapid rotation of the bow. In this scenario, a rapid yaw rotation may still occur, although significantly dampened by the effects of the change in CLR.

B2. Penetrations

Small boat collisions which involve only a penetration, are believed to be relatively rare occurrences. The classic example of a pure penetration accident would be a low profile 19 foot jet boat traveling at high speed striking at 90 degrees the hull of a large sailboat or cruiser. Penetrations are most likely to occur when the bow of the bullet boat strikes well below the top of the surface impacted. This is also dependent upon the strength of the struck surface at the upper edge.

Figure 9-4a shows a situation that could result in either an over-ride or a penetration. The bow of the bullet boat will initially deflect the hull surface and possibly penetrate a slight distance. At this point, the bow will either drive straight through the hull side or begin to ride up and over the remainder of the boat, depending upon the following factors:

a. the rake of the bow of the bullet boat;
b. the stiffness and strength of the hull side;
c. the strength of the upper edge of the impacted surface.

Once penetration has begun, the rake of the bow of the bullet boat will serve as a wedge, tending to drive its bow upward. This will only occur if the lower edges of the target boat's hull side offer significant resistance in the vertical direction. In other words, the target boat's hull sides must be strong enough to serve as a ramp for the bullet boat for an over-ride to occur. As the bullet boat's bow begins to move upward, the foredeck of the bullet boat may begin to push against the deck edge of the target boat as shown in Figure 9-4b. It is possible at this point for a large section of deck cap to be lifted from the target boat's hull. If the deck edge of the target boat is of sufficient strength, the momentum of the bullet boat will be directed through, instead of over, the target boat. The depth of penetration then becomes a function of the density and strength of any structure in the path of the bullet boat. Accidents have occurred where the bullet boat has made it through both hull sides of the target boat.

B3. Over-rides

An over-ride occurs when either part or all of one boat rides up over another vessel. For the sake of discussion, we will refer to the bullet boat as the boat that ends up on top, and to the target boat as the one on the bottom. An over-ride can occur in most any accident scenario in which the bow of the bullet boat has a chance to ride up on any structure of the target boat and the bullet boat has sufficient speed.

Over-ride accidents are important for several reasons. First, over-rides are probably the most common form of boat interaction in a serious collision. Second, the over-ride interaction is probably one of the primary reasons why more people are not killed in boating collision accidents. If it were not for one boat riding over the top of another, then boat collisions would probably be similar to car collisions, where the vehicles impact, deform, and separate. This type of two dimensional interaction forces each vehicle to experience much higher decelerations than an over-ride collision mechanism.

An over-ride accident can be broken down into a specific series of events, not all of which will be a part of every accident.

[Initial Contact] + [Penetration] + [Over-ride] +
[Trajectory] + [Water Re-entry]

Penetration of a hull surface and trajectory may not be a part of every over-ride accident. It is worthwhile to consider the risks to the occupants in each boat during such an accident. To the occupants in the bullet boat, the experience is not unlike simply jumping over a ramp. High speed accidents can result in long airborne flights for the bullet boat. The bullet boat may not lose much of its kinetic energy in an over-ride, even if it has penetrated the sidewall of an open motorboat. Of course, the energy lost is dependent upon many complex variables, mainly those

associated with the structure of the target boat which was penetrated. Some night time accidents have been documented where the occupants of the bullet boat were not even aware that they had just run over another vessel, but thought they may have struck a log instead. Since the bullet boat may ride over the struck vessel, the longitudinal deceleration of the bullet boat may not be severe. The vertical component of acceleration experienced during the impact is a potential problem, possibly throwing the occupants from the boat. If the impact is such that the bullet boat rolls during contact, the roll velocity can be sufficient to aid in throwing occupants out of the boat, or at least knocking them off balance. Stern impacts with outboards, and glancing blows are typical accidents that may product high roll rates for the bullet boat. The occupants of the bullet boat involved in a high speed over-ride may be at risk of injury when the boat re-enters the water. The relatively large flat surfaces of a boat hull can result in quite a jolt to the occupants when splashdown occurs.

The occupants of the target boat are at great risk of injury during an over-ride accident. Occupants may be injured by direct contact with the striking boat hull, by the propeller or lower unit, or by flying debris. They are also at risk of being thrown overboard. Occupants who see the target boat coming are sometimes able to duck low enough to avoid being struck. Over-rides often keep most of the parts of the bullet boat some distance from the flooring of the struck boat. This space may be the only place the occupants can go during the collision to avoid being struck.

The good news for the occupants of both boats is that the high accelerations and severe secondary impacts associated with typical automobile collisions are not generally present in over-ride accidents. By secondary impacts in this context, we are referring to the collision of an occupant with some internal part of the boat structure. People do get bounced around and may even be fatally injured during an over-ride accident. Based on a limited amount of preliminary data, it appears that fatalities in over-ride accidents are not generally from secondary impacts. The boat dynamics seem to be mild enough so that fatalities from occupants striking interior surfaces of the boat are limited. In some cases, serious injuries from a relatively non-severe accident may occur to an occupant from an impact with a pointed windshield frame or other sharp object. Minor decelerations which may occur to either boat may result in serious injuries simply because of the unfriendly nature of many boat interiors.

B4. Contact Only, No Penetration

Occasionally, two boats may come into contact with each other without creating an over-ride or penetrating a hull surface. Obviously this can occur at very low speeds, but it can occur at higher speeds as well. A scenario of this type may occur when two boats are traveling on intersecting courses in roughly the same direction. One or both operators realize their impending fate at the last instant, and execute an evasive turn. Their hull sides may contact briefly and then separate with nothing more than a

little paint transfer. This particular scenario has been documented. It appears that as long as the collision can be limited to contact, without penetration or over-rides occurring, the risk of injury or death is less than for other scenarios discussed in this section. Perhaps the greatest risk is that the occupants may be thrown out, or that the operator of one or both boats may be knocked off balance and lose control of the craft.

II. Collisions With Fixed Objects (CWFXO)

The tendencies and characteristics of these accidents are discussed in great detail in Chapter 4; however, we will briefly address a few of the most general tendencies with CWFXO accidents. The results of the collision vary greatly depending upon the boat involved and the object struck.

When a boat strikes an object it will decelerate. In addition to the impact velocity, the rate of deceleration is dependent upon the boat structure, and the rigidity of the object. All other factors being equal, a boat will generally experience a less severe deceleration during an impact with a non-rigid object than a rigid object. Examples of each are a wooden boat house, and a concrete bridge piling. The deceleration is also dependent upon the "centeredness" of the impact. A centered impact occurs when the principal direction of force (PDOF) is in line with the CG. For CFXO accidents, a centered impact can be thought of as a head-on impact, while an eccentric impact is an off-center impact, closer to a glancing blow.

In CWFXO accidents, the occupants may be thrown out, or they may stay in the boat. Occupants that stay in the boat are at risk of injury due to secondary collisions that occur when they strike some part of the boat interior. The degree of injury is further dependent on the object struck and the deceleration rate involved. Impacts involving relatively low deceleration rates can result in serious injury if the occupant strikes a sharp object. Consider the following hypothetical scenario: A 19 foot I/O strikes a tree at only 15 mph, and the operator travels forward and strikes his forehead on the sharp sheet metal of the windshield frame. An occupant who is standing is thrown off balance and cuts his abdomen on the corner of the walk-thru windshield. This is an example of how severe injuries can occur in relatively low speed accidents.

Chapter 4 showed that many of the objects struck in CWFXO accidents are not seen prior to the impact. Stumps and underwater rocks are examples. These are particularly dangerous, in part, due to the surprise factor. The operator almost never has a chance to see the stump before the impact, precluding the opportunity for any evasive action. As a result, neither the operator nor any of the occupants are prepared for an impact, and may be more easily thrown off balance or thrown overboard.

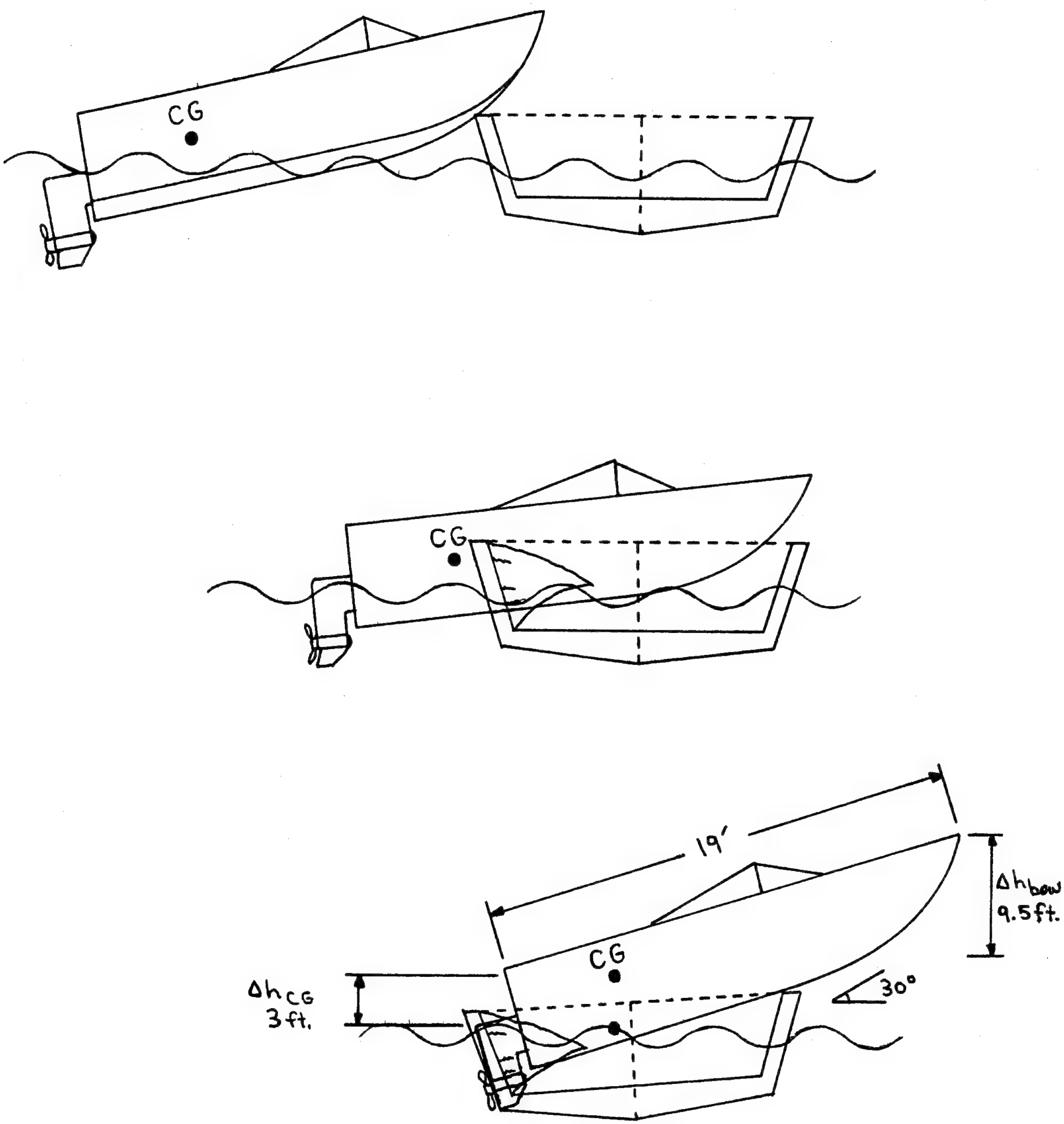
III. Collisions With Floating Objects (CWFLO)

Perhaps the most common factor discovered in the analysis of these accidents is that the object struck is almost never positively identified. This fact was discussed in Chapter 4, which limited the analysis only to fatal accidents. Additional insights into this category could be obtained by studying non-fatal accidents as well. It is difficult to develop a list of general trends for this type of accident based on the limited data obtained. The main concern when analyzing this accident in the future is to first determine that it is correctly classified.

9.3 Conclusions

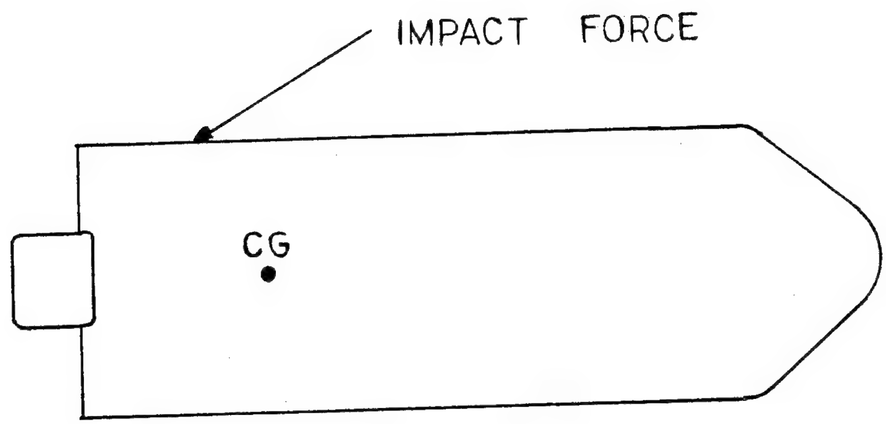
We are just beginning to learn the characteristics of certain types of collision accidents. Generalizing what happens in certain CWAV accident scenarios can help an investigator know what to look for when analyzing an actual accident. It may be possible, in the future, to identify which scenarios result in the most fatalities. This may show where future efforts in improving boating safety should be directed. This is where some sort of classification system of accidents may help. In the meantime, it appears that even minor improvements in boat interiors, with regard to occupant protection, may help to reduce injuries. Many manufacturers have already begun the common sense process of padding and rounding interior surfaces. Future efforts may be again directed toward visibility, navigation light requirements and enforcement, and operator education.

CWFXO and CWFLO accidents are distinctly different from CWAV accidents. The first two are frequently dependent upon the condition of the waterway in which the boats are traveling. Even the most educated operator in good weather can fall victim to an unmarked stump in a lake. It is important to realize that at least some CWFXO accidents can be prevented by proper marking of waterway hazards.



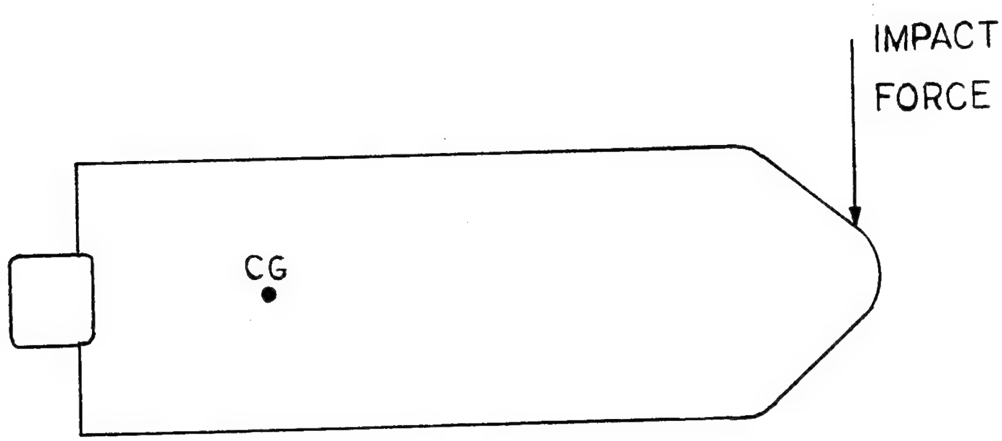
Side Impact with a Stationary Target Boat. The Change in Height of the CG is Much Less than the Change in Height of the Bow.

Figure 9-1



Glancing Blow Possibly Resulting in Minor Target Boat Rotation.

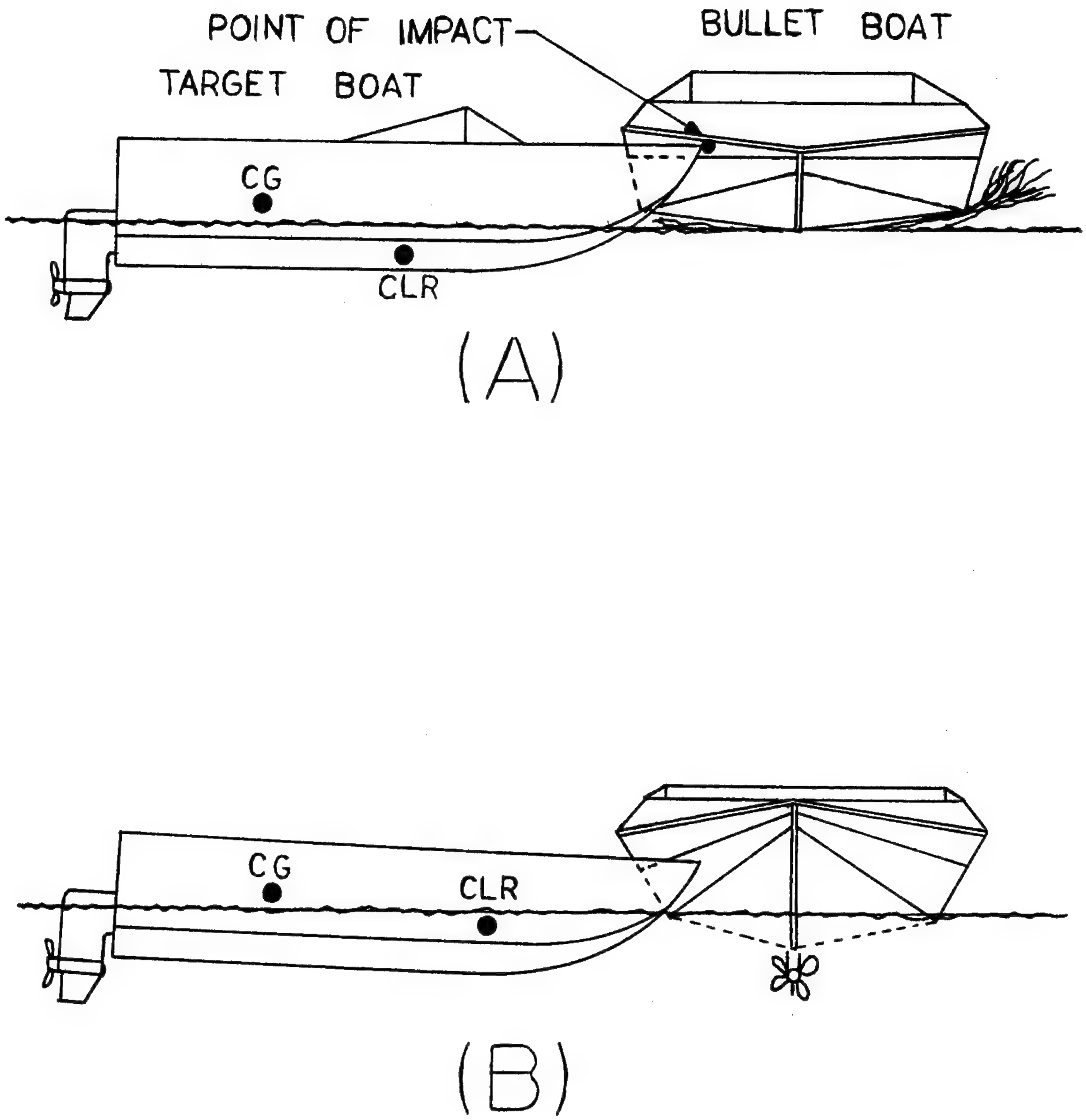
(A)



Glancing Blow Possibly Resulting in Rapid Target Boat Rotation.

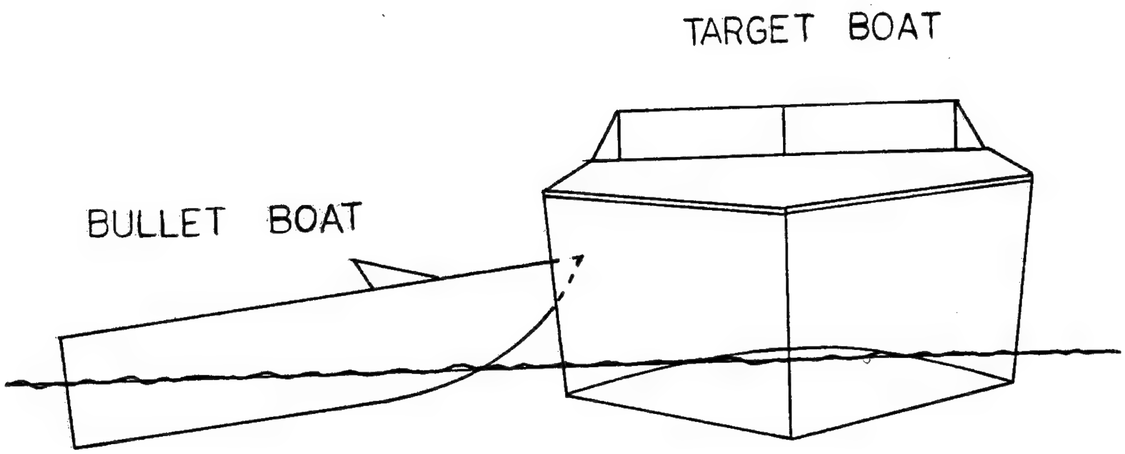
(B)

Figure 9-2

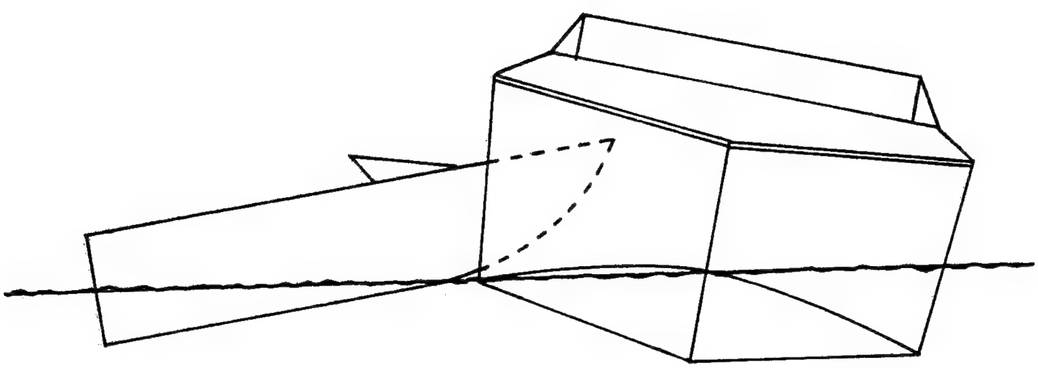


Rotation of the Target Boat can be Dampened if the Bullet Boat Begins to Ride Over the Bow. Depressing the Bow Causes the CLR to Shift Forward, Further Dampening the Rotation.

Figure 9-3



(A)



(B)

A Penetration Collision That Could Result in an Over-Ride.

Figure 9-4

CHAPTER 10

UNDERSTANDING AND DOCUMENTING ACCIDENT DATA

10.0 Introduction

Accidents cannot be reconstructed unless all the necessary data required are made available for analysis. This chapter will provide an overview of the techniques for documenting data from boats, and when applicable, from the accident scene. We will also discuss the various types of damage and what they could mean. Every scratch, every paint smear, every crack, and every inch of damage tells a story about what happened. We are only beginning to understand how to get the details of that story, but much of what has been learned is recorded in this chapter. After all, it is important to have an understanding of what you are documenting in order to perform the best possible job of recording the relevant data.

Proper documentation of accident data is the most important part of any accident investigation. Yet, the investigator is faced with many challenges at the scene of the accident that are often a higher priority than documentation. Providing assistance to the injured and the protection of life and property from further risks are part of those priorities. Preservation of the accident scene and the documentation process must of course be placed into its proper perspective. Once the higher priorities are addressed, it is extremely important to preserve the accident scene and begin proper documentation procedures.

Many of the difficulties encountered in gathering data associated with a boating accident were discussed in earlier chapters. The accident location is often unknown. One or both boats may be sunk or already removed by their owners. In many cases, the investigator may not even find out about a serious accident until hours or possibly even days later. All of these factors make it more difficult to obtain documentation of un-altered evidence. There will always be circumstances beyond the investigator's control that prevent the accident from being properly documented.

All too often accidents in which all the information was made available to the investigator were not documented properly, making a reconstruction virtually impossible. Our goal is to provide sufficient guidelines to the investigator to help ensure that all the essential information is obtained so that the accident may be reconstructed.

The procedures and guidelines in this section assume that the investigator can start out in an ideal situation. This means that in a CWAV accident, both boats are available. It generally means that access to the accident scene is also available, which is especially important in CWFXO and CWFLO accidents. We will also assume that the investigator can arrive on the scene shortly after the accident.

The investigator usually has limited time and resources when attempting to document the damage relating to a boating accident. It is important to realize that all of the procedures outlined in this chapter are not required for every accident. It is up to the investigator to prioritize the areas that need to be documented as they relate to the accident at hand. This chapter does not include all items that may need to be recorded for every accident, but it should help to stimulate the investigator's thoughts on what information needs to be recorded.

Witness interviewing techniques are not covered in this report. It is not because they are not important, but because it is a topic that has generally been covered in other texts before. It is also a standard part of virtually all law enforcement officers' training. We want to develop techniques for reconstructing accidents based purely on the physical evidence when possible. Relying too much on witness statements may tempt the investigator to make the evidence fit the statement, instead of reviewing the evidence to determine the actual sequence of events.

10.1 Purpose and Goals of Documentation

Why does anyone bother to do an accident investigation? The common answer is so that we know what happened. The information can be used to improve boater education, identify statistical trends, develop safer boats, and assist in litigation. We are usually interested in the sequence of events that lead up to the accident, the events that occurred during the accident, and the events which happened immediately after the accident.

The purpose of providing documentation of the accident data is so that a reconstruction of the sequence of events regarding the accident can be performed. In particular, we are usually trying to answer certain questions regarding how the accident occurred. Common goals of a reconstruction are to answer the following questions:

a. What was the approximate speed of each boat at impact? We at least need to know if the boats were on plane, off plane and level, or in transition between planing and off plane (bow up).
b. What was the impact angle?
c. Where was the initial impact point?
d. Were the navigation lights operating? (for night time accidents when relevant)

e. What happened to the occupants?
f. What were the locations of the occupants prior to the accident?
g. What happened to the occupants during the impact?
h. Were the occupants thrown overboard, or did they stay on the boat?
i. If they were thrown overboard, did they drown? If so, were they wearing a PFD? If not, where were the PFDs located? Were they readily accessible?
j. If the occupants stayed on board, what caused their injuries?
k. For CWFXO and CWFLO accidents, what was the object struck?
l. Where did the accident occur?
m. What were the causes of this accident?
n. What could be done to minimize the chances of this type of accident happening again?
o. Who was at fault? What were the contributing factors?
p. Was mechanical failure involved, for example, loss of steering?

There are other questions that often need to be answered in an accident investigation; however, we will be concentrating on those that relate to physical evidence surrounding the boat, the occupants, and the accident scene.

10.2 What Are You Looking For?

It has often been said that if you do not know what you are looking for, you are not likely to find it! Nowhere is that more true than in the field of accident reconstruction. Simply stated, you are looking for anything that will help you to determine the sequence of events. This can include items such as physical damage, instrumentation readings, throttle settings, and the list goes on. It is the understanding and interpretation of the physical damage that is often the least understood and most difficult part of the investigation. In the next few sections, we will concentrate purely on understanding physical damage. Other important areas such as instrument readings, navigation lights, and so forth will be also be covered in this chapter.

When examining a boat, there are several types of damage that are commonly present. These types are listed below:

1. Contact damage
2. Striations
3. Imprints
4. Induced damage
5. Items that shift, move, deflect, or provide PDOF (principle direction of force) indications
6. Secondary impact damage (occupant impacts or other loose objects)

We will briefly explain each of these types of damage and how to recognize them.

10.2.1 Contact Damage - What It Is and How To Identify It

Contact damage is the result of two objects coming into direct contact with each other. Usually, the materials involved will bend, break, shatter, crack, or deform. Since much of the damage which occurs to a boat in a collision is not from contact damage, additional techniques are needed to identify a damaged area as being caused by contact with the other object. Contact damage can usually be identified because material from one object has been transferred to the other. This may be in the form of paint transfers, or rub rail marks for example. In some cases, pieces themselves may be transferred. As an example of the latter, a portion of a decal on the hull of one boat was embedded underneath the edge of a cleat on a second boat. During the course of our field accident investigations, types of contact damage were noted to be common to many accidents. We will look briefly at some specific types of contact damage, and how to identify them.

10.2.1.1 Contact Damage- Rub Rail Transfers

Many small boats contain a rub rail, which consists of rubber or a similar material set inside an aluminum or other metallic frame that extends around the perimeter of the boat. When the rub rail makes contact with another boat during a collision, the transfer of the rub rail material to the hull of the second boat may be easily identified. Rub rail transfers often have the following characteristics:

- short black streaks on the hull
- may leave a sticky black textured mark
- the transferred rubber is easily scraped off

The rub rail may show signs of being scraped or rubbed, but seldom retains any visible coloring or paint transfer from the other boat where contact was made. In other words, you can not usually look at a rub rail, and tell what color of gelcoat it came in contact with on the second boat.

When the rub rail comes in contact with the fiberglass hull of the second vessel, the friction may produce sufficient heat to soften or melt the rubber in the rub rail. This facilitates the transferring of small amounts of rubber to the fiberglass hull of the other boat.

10.2.1.2 Contact Damage - Outboard Motor Cowlings

If the outboard motor cowling on one boat is damaged, it is wise to begin to search for the matching damage on the other boat. Many times the outboard motor cowling is painted a color that is different from any other color on the boat. As such, it is often easy to identify the marks on the hull of the other boat where this contact was made. Black motor cowlings on light colored hulls are often especially easy to identify. The shape of a typical outboard cowling along its top often makes a pair of easily identifiable marks. Most motor cowlings have a "step" in their design at the forward edge of the cowling that is noticeable when viewing a profile of the motor. This step typically leaves a pair of smudged streaks against a hull surface when struck in a transverse direction, and contacted near the front of the cowling. The resulting marks may still be identified, though they are not quite so discernible, even if the angle of motion of the bullet boat is not parallel to the face of the motor cowling. Note that the steering angle of the outboard at the instant of contact will affect the appearance of these marks.

The appearance of marks from outboards is not always easy to identify. Even with black cowlings and light colored hulls, the marks may only appear as a light black smear. It is often difficult to find clear evidence of paint on the outboard cowling. Paint is not easily transferred to the motor cowling from the hull of a striking boat. Therefore, examination of the outboard cowling alone will not usually reveal which part of the striking boat came into contact with the cowling.

10.2.1.3 Contact Damage - Metal to Fiberglass Contact

It is common in over-ride accidents for the windshield frame, metal hand rails, or other metal surfaces, of the struck boat to come into contact with the bottom of the hull of the bullet boat. When metal surfaces impact or scrape across a fiberglass hull, the result is generally quite different from when two fiberglass surfaces rub across each other.

A common example of this occurs during an over-ride, when the hull bottom of the bullet boat scrapes across a metal windshield frame. If the direction of travel is along the direction of the metal frame, the result is typically a deep gouge or scratch. These scratches may even penetrate through the first layer of fiberglass in the hull. If the motion of the bullet boat is across the metal frame, the result is a wide scrape that usually leaves jagged edges of fiberglass for the entire contact area. The depth of this damage is usually sufficient to remove all of the gelcoat, and penetrate to raw fiberglass. The coating of the aluminum may leave silvery marks along the contact area.

Deep gouges, cuts, or jagged scrapes in a fiberglass hull, which may be surrounded by striation marks in the same direction, are usually an indication that something metal struck the bottom of the hull. These marks commonly occur along the outboard chines of hull bottoms, and along the centerline at the bottom of the vee. These marks may also appear on the edge of spray rails molded into the hull.

10.2.1.4 Contact Damage - Paint Transfers

Paint transfers are one of the most common characteristics of contact damage. Paint transfers often appear as scratches of a color different from the surrounding surface color. These transfers usually occur when two surfaces come in contact and slide across each other. The result is that they often swap small portions of paint, colored decals, or other surface material. These marks are useful because they usually indicate the color of the surface that made the contact. This is especially helpful in boats that have more than one color on their hull.

One must be careful in identifying paint transfers. The outer color of a boat hull may be different than a series of base coats underneath. As a result, when the outer coat is scratched, what is visible as a different color may be the base coat below. It is important not to confuse these scratches with paint transfers. In these cases, the scratch may be indicative of contact damage, but the color of the scratches is not that of the other boat!

10.2.1.5 Contact Damage - Skeg, Propeller, and Lower Unit

One of the most characteristic marks that is found in a CWAV accident involving an over-ride is the mark left on a hull where the lower unit penetrated the hull. This mark was discussed in some detail in Chapter 6. Figure 6-1 illustrated the characteristics of this damage. For sake of completeness, we will repeat the key concepts here as they apply to documentation of damage. These concepts apply to both inboard/outdrive and outboard powered boats. In most of the material that follows, descriptions of damage that refer to the outdrive also apply to outboard powered boats.

In a CWAV over-ride type collision, the lower unit may penetrate the hull of the struck vessel. In partial over-rides, the lower unit may never make contact with the struck boat, especially if the struck boat is moving. When the lower unit does penetrate the hull side, it leaves several identifying marks as follows:

- A hole (where the torpedo of the gearcase penetrated) with a vertical slit extending below it where the skeg penetrated. If the gearcase strikes high enough the slit from the skeg may be all that is visible;

- This area is usually below other obviously damaged areas, (it may be the lowest damaged area on the struck boat);
- Shaved areas of fiberglass around part of the gearcase hole caused by one or more propeller blades passing through that area. Propeller blade cuts will be at a distinctly different angle than the path of the skeg due to the high rotational speed of the propeller blades.

It should be noted that this area is not always as obvious as one might expect. The flexible nature of fiberglass may have caused much of the deflected material to return to its original orientation, leaving only relatively small openings and minor damage readily visible. Close examination will usually reveal where large sections of fiberglass had folded out of the way.

Occasionally when an outdrive or outboard motor passes over an object such as a swim platform (which may occur during a stern impact), a deep cut created by the skeg is all that is visible. Cuts in adjacent material that are roughly transverse to the skeg cut may be made by the propeller.

Some researchers have speculated on using the distance between propeller cuts in material to estimate boat speed. While other useful information can be gained from a clear set of propeller and skeg marks, speed is not one of them. The distance between propeller cuts is relatively constant for most forward boat speeds, and is based on propeller pitch and slip. It is also possible that the speed of the rotating propeller varied slightly as it cut through the material. Also when the propeller leaves the water under power it will quickly increase in rotational speed (rev up). The effect is to create blade cuts that are much closer together than would be normal for that boat speed. Thus, the best use of these damage patterns is to positively show the location at which the outdrive penetrated the struck boat.

10.2.1.6 Contact Damage - Initial Impact Points

To reconstruct a CWAV accident, it is extremely helpful if the initial impact point can be determined. This is perhaps one of the most difficult determinations to make. If the struck boat is stationary, or traveling very slowly, the portions of the hull where the bow of the striking boat made initial contact are often smashed into oblivion. This is also true of impacts where the struck boat has a low relative velocity when compared to the striking boat. Evidence of where the outdrive or outboard penetrated the hull may be located, but the exact point where the bow of the bullet boat made contact is not generally discernible. This is because the area where the initial contact occurred was further penetrated by the remainder of the bullet boat, including the outdrive.

Generally, the initial impact point on the struck boat can be assumed to be near the area where the outdrive penetrated if all of the following conditions are true:

- The velocity of the struck boat is zero, OR the velocity of the struck boat is relatively low (such as minimum idle speed of two to three mph) when compared to the velocity of the bullet boat
- The bullet boat's velocity vector was parallel to its longitudinal centerline (i.e., the bullet boat was not skidding at all sideways at impact)
- The bow of the bullet boat was not deflected laterally by striking any stiff structures on the struck boat
- The struck boat does not rotate significantly during the impact

When the struck boat is moving at a significant velocity when compared to the bullet boat, the initial impact point may be more visible. If a CWAV accident involves a side impact, then it is possible that the only part of the bullet boat which strikes the hull of the target boat in the area of first contact is the bow. In other words, the remainder of the bullet boat does not pass through the same area as that which is created by the bow at first contact. This means that marks which indicate bow contact may be left intact on the struck boat. One example of this is a notch left in the fiberglass of the struck boat by the bow eye of the bullet boat or an indentation created by the sharp "V" of the bow of the bullet boat.

It is generally assumed that the point of first contact of the bullet boat is the bow. Certain situations however, especially in collisions where the impact angles place the centerline of the two boats nearly parallel with each other, lead to initial contact areas of the bullet boat off center from the bow centerline. In other words, the forward sides of the boat may make first contact. There are several techniques you can use to understand how this is possible. One is to examine the top view of an outline drawing of the bow of both boats. By placing the drawings at various angles to each other, it becomes apparent that a range of angles exist for which the leading edge of the bow will not make contact first, if at all.

Perhaps an even easier method to visualize the concept is to use two model boats of the same scale, and study their contact areas for various impact angles.

10.2.1.7 Damage Not Related to the Accident

Not all damage that appears on a boat is directly related to an accident. Non-accident related damage can usually be categorized into one of three categories as follows:

- Damage which occurs during recovery of the boat
- Normal wear and tear
- Previous minor accident

These items are listed in approximate order of importance based on limited field experience. In a serious accident, a vessel may be heavily damaged. If the boat has capsized, sunk, swamped or beached, some additional damage to the boat will generally occur during salvage and recovery of the vessel. If the boat is still floating upright after an accident, it may be recovered onto a trailer with little additional damage.

On-scene photos or videos of a boat which has been swamped or capsized, or even sunk (if it is at all visible) can be important in helping to separate damage which was done during a recovery operation from damage which occurred during the collision. For the same reason, it may be beneficial to photograph or videotape the recovery operation. Views of the boat as it is being recovered may prove valuable in showing that certain damage was either present or absent at a certain point in the recovery. Such footage can also help an investigator to formulate hypotheses regarding the potential for the recovery operation to have created certain questionable damage. For example, if a capsized boat is shown being drug across a rocky shore bottom, it will certainly help to show what caused a series of scratches found on the side making contact with the rocks.

The importance of procedures in the preceding paragraph should not be underestimated. In one particular accident, photographs of a capsized boat (which was still in the water) taken shortly after the accident clearly showed a set of striation marks on the aft end of the bottom of the hull. These marks were crucial to the accident reconstruction, and showed that they were not caused by the recovery operation.

It is also important to distinguish contact damage which occurred during an accident from that which may be part of normal wear and tear on a boat. Most seasoned boats will accumulate scratches on the bottom of the hull over time. They may be from beaching, grounding, or an occasional goof when loading the boat onto the trailer. Boats that spend much of their time tied to a dock may also accumulate minor scratches and dents from rubbing or banging against the dock's surfaces. Another source of contact damage results from the new boat owner who has a few minor docking accidents. These minor mishaps are seldom serious, but may result in paint transfers, or minor damage to a boat that can confuse an accident investigator when examining a boat that has been involved in a subsequent more serious accident.

While it may not happen frequently, it is always possible that damage which appears on a boat may be the result of a previous accident. Depending upon the nature of the damage, it may not be possible to tell when the damage occurred, or even if it is definitely a result of the accident being investigated. There are several methods that may be of help in assessing the possibility that certain damage was caused by a previous accident:

- get the history of the boat from the current owner
- obtain photographs of the boat prior to the accident

- check with local repair yards or marinas in the area regarding work that may have been performed
- check with previous owners about the boat's history

It may be apparent that certain types of damage occurred long ago. Signs of rust, corrosion, or even the amount of dirt in a damaged area can be indications that damage was not the result of a recent event.

While it may not always be possible to determine if certain damage is related to the accident under investigation, simply being aware that it may not be related to the current accident will help you from making dangerous assumptions during your investigation.

10.2.1.8 Contact Damage - Summary

Obviously physical damage can be a result of two surfaces coming into contact with each other. Experience has taught us that just because physical damage is present, it does not mean that it is contact damage. Thus, we need other ways to identify contact damage. The characteristics described in this section are frequently present on surfaces damaged by contact with another object. None of these characteristics, or all of these characteristics may be visible in a local damaged area caused by contact damage. No hard and fast rules are available to prove that a certain area was damaged by contact with another object if none of these characteristics are present. Experience has shown that generally, at least some of these identifying characteristics are present in most contact damaged areas. Contact damage is important, especially in CWAV accidents. It shows where two boats actually touched each other during the accident. This information helps to establish the orientation of the two boats during the accident, and is thus critical to a reconstruction. It is important to distinguish contact damage from induced damage because otherwise inaccurate conclusions may be drawn regarding the boat's orientation during the contact phase of the collision.

10.2.2 Striations

Striations are one form of contact damage, but can contain so much information that they are worthy of discussion as a separate topic. Striations are essentially scratches in a surface. They are caused by friction, abrasion, scraping or rubbing against two surfaces. The existence of striations shows that the two surfaces which made contact were not traveling at the same velocity while they were in contact. This is a characteristic of a partial impact. Striations may be virtually non-existent in a full impact. Striations are normally limited to surface damage. They are important because they indicate the relative direction of movement of the two surfaces while they are in contact with each other.

Striations come in many forms and can be analyzed for different purposes. Some striation marks are really a pattern that

can be traced back to the particular object that created them. Striations can also be useful for interpreting the relative movement of one boat while in contact with another. Curved sets of striations may be indicative of the following:

- One boat rotated while it was in contact with the other
- The object which created the striations moved, deflected, or was significantly displaced as the marks were made
- The velocity of one or both boats changed significantly while the boats were in contact with each other

A great amount of detail is given to the analysis of striation marks in Chapter 12.

10.2.3 Imprints

Imprints are also a form of contact damage. They may occur when two objects collide, and attain the same velocity, even if only for an instant. An imprint occurs when a striking object leaves an impression on the surface struck that resembles the shape of the striking object. Accident number nine in Chapter 13 shows several examples of imprints. The deformation of a hand rail struck by the bow eye of a boat, and the outline of the shape of a seat on the bow of a striking boat are two examples of imprints.

Imprints are useful because it is usually possible to match the imprint with the object which caused it. This helps to positively determine the orientation of the two boats during at least one point of the collision.

10.2.4 Induced Damage

During some collisions, the struck boat may show signs of damage from literally one end to the other, even though only a small part of the craft was directly struck by the other vessel. Damage that is not caused as a result of direct contact with a striking object is normally called induced damage.

Common examples of induced damage are separation of the hull and deck joints, and stress cracks in fiberglass hulls well away from the impact point. It is important to realize that severe damage to certain parts of a boat's hull may not be caused by contact with a striking vessel. During a collision, the hull sides may flex a large amount, and then spring back to the original position. If the displacement is large enough, entire hull sections may literally act as though they are hinged about the closest hardpoints. Stress cracks may appear at these hardpoints in a direction parallel to this apparent hinge. Induced damage is important if only because it is necessary to distinguish it from contact damage. Remember that hardpoints are areas where the boat structure, such as the hull, are rigidly supported by a bulkhead, stringer, or other strong support. The softer hull skin tends to flex around these areas.

10.2.5 Items That Shift and Provide Indications of Thrust Direction

When two boats collide, the contact forces may be great enough to result in a significant deceleration by one or both boats. If the primary thrust direction results in an eccentric impact, rotation of the struck boat may also occur. Refer to Chapter 7 for more information on eccentric impacts. Often the deceleration is enough to cause displacements of various objects or structures inside the boat. Seats, engine covers, and the contents inside a storage compartment may all be shifted in a certain direction. These objects will have a tendency to shift in a direction that is exactly opposite of the local acceleration vector. It is also important to understand that the local acceleration vector may change both in magnitude and direction as a function of time throughout the collision. This is especially true for eccentric collisions involving high rotation rates. Thus, the displacement of an object such as an engine hatch may be the combined result of varying accelerations. If no rotation occurs during the collision, the acceleration vector is directly opposite the direction of thrust created by the impacting vessel. This is useful because we may be able to estimate the thrust direction and thus the direction of impact of the other vessel, if we can document direction of shift of various structures or objects.

Items that shift and indicate a thrust direction come in many varieties. During one accident, a small table supported by a single round post in a cuddy cruiser broke loose during the impact. The post was leaning in a direction that indicated the thrust direction during impact. In this particular accident, the post was leaning toward the impact point.

These concepts are important because you should document any object which shows signs of shifting from its original position. The documentation of a seat frame, or an engine hatch cover which has shifted from its original position should be photographed with a scale reference, and the displacement from its original position in the longitudinal and lateral directions should be recorded.

The investigator is encouraged to be cautious in using displaced objects to estimate thrust direction on boats which capsized, swamped, or sunk after a collision. Often forces which occur during one of these events may cause displacement of an object which could be mistaken as that caused by deceleration.

10.2.6 Secondary Impact Damage

We know from basic physics that objects tend to remain in their current state until acted on by some outside force. Thus when a boat traveling 40 mph strikes a concrete wall, the boat may stop rather suddenly, but the occupants and all loose objects in that boat will want to keep traveling at 40 mph. The result is that the occupants will impact some interior portion of the vessel with great force, or they may be thrown clear of the boat entirely. In case of the former, signs of this secondary impact are often left

behind. The operator may impact the steering wheel and windshield. Passengers may strike other parts of the boat interior. In either case, any signs of secondary impact should be carefully documented.

Secondary impact signs left by the operator are usually the most easily identified. Damaged steering wheels and windshields are common signs that the operator MAY have struck this area. One must be careful not to assume that it was the operator who caused such damage. In CWAV accidents, passengers have been known to be thrown in the general direction of the operator's position, and may have been responsible for the interior impact damage. Matching of injuries on victims' bodies with objects struck may prove which person struck which objects. This information is important because it helps to identify the general motion of the occupants relative to the boat during the impact.

One must also be careful not to confuse secondary impact signs with contact damage caused by the other vessel. If, for example, a hard plastic steering wheel contains deep cuts or shows signs of significant abrasion, it was most likely struck by a harder object. An object which suffers an impact with an occupant may bend, break, crack, or deform, but it will not generally contain surface cuts, deep gouges, or abrasions. Marks such as these are almost always caused by contact with another hard or harder object.

Secondary impact signs can be very difficult to detect. Boat interiors are frequently full of hard fiberglass surfaces which do not leave much of a record of what objects might have impacted them. Any cracks, noticeable deformations, or other signs of any type of damage should be photographed in the occupant interior. It may be easier to examine the injuries of the occupants and then determine the object struck than the other way around. Windshield corners, brackets, steering wheels, and other surfaces may leave distinct marks in a victim. Experienced medical personnel can be most valuable in assessing the type of object struck necessary to result in a certain type of injury.

It is extremely important to attempt to determine the location of all occupants in a boat before a collision, and to determine what happened to each of those occupants during and immediately after a collision. While this may not always be possible, it can be of great help in the investigation. It is always important to determine, at a minimum, if people were thrown overboard, or if they stayed in the boat. Caution is encouraged when occupants of a violent collision try to describe exactly which way they were thrown. It is extremely easy for a victim to become disoriented during such an event, and such descriptions should not be relied upon too heavily during a reconstruction. Credibility of the account increases if several other witnesses or occupants provide consistent statements.

Secondary impact signs may not be caused by the occupants. Any loose object in the boat may strike another part of the boat's interior and cause enough damage to be detectable. Items mounted on bulkheads such as fire extinguishers or other equipment may break loose during an impact, and strike another nearby surface.

If screw mounted components rip free, examination of the screws and the mounting area often indicate the direction of travel. Examination of storage compartments and engine compartments may show that objects stored inside these areas struck an adjacent surface hard enough to cause damage, thus providing indicators of thrust direction.

10.3 Where Do You Look?

Much of the answer to this question can be found in Section 10.2. Knowing what to look for answers the question of where to look for many types of damage. There are a few places that investigators often fail to examine in an analysis. We will discuss those areas worthy of explanation and present the remaining ones in the form of a checklist.

10.3.1 Hull Bottoms - Documenting Striations

When an over-ride collision occurs, the bottom of the bullet boat passes over at least some portion of the struck boat. The result is a series of striations and other damage that are left behind on the bottom of the hull of the bullet boat. These striations are extremely important in a reconstruction and must be properly documented.

If the striations are going to be used in a reconstruction, then the precise location and angle of each must be carefully documented. Careful photographs taken of the hull bottom from a 90 degree angle provide good information with which to work. We will see how to use these striation marks in a mathematical analysis in Chapter 12, but first we must learn the best way to document them.

Taking photographs at a 90 degree angle of the hull bottom is not an easy task. The boat must either be turned on its side, or suspended from a cradle. Occasionally you can obtain sufficient hull bottom photos when the boat is on a trailer. Parking the trailer over a pit can enhance the working conditions significantly. If it just so happens that you arrive at the scene, and the boat is floating capsized, you have an excellent opportunity to take photographs of the hull bottom! In order to be useful, any photos taken must have a scale, such as a tape measure, visible in the photograph.

It is often true that the striations are visible to the naked eye, but are not pronounced enough to show up on film. When this occurs, you must use some technique to ensure that the critical information shows up on your photographs. Striation patterns often appear as a large number of individual scratch marks of varying lengths running parallel to each other. The most important information to obtain on striations is their direction, and location on the hull. The exact number and length of each striation is not generally valuable unless you are trying to match a particular striation pattern to a particular object on the other boat.

A variety of techniques are available to assist in helping striation marks to show up on film. Certain dyes and special inks are available to help make individual cracks and scratches more visible. We were not able to try these techniques in the field on fiberglass boats, but labs specializing in non-destructive testing have used such procedures on a variety of materials in the past. One crude technique we were able to use was to place tape next to the striation marks. The tape used was always a contrasting color to the gelcoat. The direction and length of the tape matched as close as possible the striations themselves. How well this method would stand up in court is unknown, since the photograph is not of the actual damage but of pieces of tape placed on the hull by the investigator. It does provide a simple method that anyone can use in the field to document the length, location, and direction of striation marks. This tape also shows up well in overall photographs taken from some distance away. The tape we used was either colored electrical tape, or in many cases masking tape. Care must be taken when applying the tape to keep it parallel to the striations. If the striations are curved, this technique becomes more difficult to employ, especially if you are using a wider tape such as masking tape. For maintaining a tape pattern parallel with curved striations, it may be useful to keep a roll of pinstriping tape in your toolkit. This tape is available in 1/16 or 1/8 inch widths at many auto parts stores. The tape also comes in a variety of colors, though one roll of black and one of white will serve most needs well. It is the same tape used for detailing automobiles and is designed to be placed in curved configurations.

Using markers to enhance striations is not recommended because it is almost impossible to draw a straight line free-handed on a curved boat surface. Following the generally straight lines or large sweeping curves of striations is much more easily accomplished with tape than with a marker. Tape can also be easily removed once the necessary photographs are made.

Documenting the location and direction of striations is extremely important. You must know how far forward or how far back on the hull bottom you are from a distinctly measurable reference point. Equally as important, you should know the lateral location of the marks. This is best measured from the centerline of the boat, but may be measured from the hull chines if that is the best that can be done. The problem with measuring from the hull chines is that it requires some additional careful measurements to determine the distance of the hull chine inboard in the horizontal plane from the outermost perimeter of the boat. This information is needed to construct the damage diagram discussed later. The use of a protractor can be helpful in estimating the angles of the striations. If the striations are essentially straight, you can estimate the angles of the striations relative to the centerline of the boat by documenting how far from a fixed location the beginning and the end of the striation marks are located.

Probably the best method for documenting the angles of striations relative to the boat centerline is to take photographs. The photographs of striations on the hull bottom should be taken perpendicular to the bottom with the centerline of the boat clearly

documented. The angles of the striations can then be measured with a protractor.

10.3.2 Hull Sides

The sides of the hulls of both boats may be full of information. Paint transfers on the surfaces of the bullet boat can provide data on what part of the target boat was struck first. The color of the paint on or near the bow of the bullet boat will generally indicate the color of the hull, and potentially the location, where the target boat was first struck. If the other boat is all the same color, this is not particularly helpful information; however, if the color smeared on the bow of the bullet boat is unique to a certain location on the target boat, the initial impact point may be determined.

The sides of the target boat are also full of information. The type of damage, and the general shape of the deformed hull side may indicate a relative impact angle. The shape of the cutout made on the side of the target boat which was involved in an over-ride is indicative of the impact angle, if we can clearly discern an outline of the hull penetration areas.

It is worth pointing out that if a boat with twin engines strikes another vessel, that the location of the skeg/propeller penetrations on the target boat is extremely valuable. The distance between the skeg marks on a hull side for example, can help to determine the impact angle.

For almost all collision accidents, the sides of the hull of both boats should be carefully examined and photographed. Look for the signs and types of damage covered in section 10.2

10.3.3 Under The Carpet

Attempting to determine the extent of damage to a fiberglass boat by examining only the outer visible areas of the hull can be misleading. It is usually necessary to examine the boat from the interior to help determine the extent of damage and answer questions about the motions and interactions of the two boats while they were in contact. Wood and metal can be your best friends when attempting to answer questions regarding the extent to which a hull may have deformed during an impact. The wood used in the construction of the boat hull, which many times is right next to the fiberglass on the inside of hull, is the best place to look. Wood and metal are better than fiberglass at suffering damage and remaining in a shape somewhat indicative of the deformation at failure. Unfortunately, these key indicators are usually hidden by carpet, padding, seats, storage compartments, and similar items, which themselves may appear undamaged.

If conditions and the environment permit, you may find it useful to remove carpet and padding from around the impacted area

all the way down to the hull interior. This procedure has worked well in accidents where the true extent of the damage to a boat was unknown, or where it was desired to determine how far another boat penetrated a hull surface. Obviously these procedures involve destructive examinations and should not be undertaken unless the legal climate permits. They should also not be undertaken until all photographs and documentation of the surrounding areas which are about to be destroyed have been completed. If time permits, it is prudent to conduct a detailed examination and document all evidence possible without destructive examinations first, and wait until photos are developed satisfactorily before engaging in destructive examinations. Videotaping a destructive examination may be useful in showing the condition of items as they are discovered in the process.

10.3.4 Other Data That Should Be Recorded

There is a variety of information that could be recorded in a boating accident. The specific information needed usually falls into one of two categories. It is either data related to damage caused by the accident, or data that helps to provide the general circumstances that surrounded the accident. Striations on the hull bottom are an example of the former, while the level of fuel in the tank is an example of the latter. This report focuses more on the interpretation and analysis of data related to damage. However, the investigator is not provided the luxury of only recording certain types of information regarding a serious boat accident. Physical data on damage, circumstantial data, and witness statements all must be analyzed and considered to perform a complete reconstruction. As a result, we have provided a list that includes many of the data items that an investigator may wish to record from a boat after an accident. Not all items are relevant to all accidents, but the checklist should help to remind the investigator of those items relevant to his or her particular situation. If attempts are made to reconstruct the accident several years after it occurrs, it will be crucial for the reconstructionists to know exactly what damage resulted from the collision and which damage was caused by the destructive examinations.

CHECKLIST OF PLACES TO LOOK FOR PHYSICAL DAMAGE

Following is a reminder of common places to check and inspect for damage following a collision. This list is intended for boats in CWAV accidents, but many items apply to CWFXO and CWFLO accidents as well.

1. Hull Bottom
   striations, chunks removed, paint transferred?
2. Hull Sides
3. Bow of Bullet Boat
   paint transfers
   striation directions

4. Bow Eye (Bent or damaged)
5. Stern (including swim platforms, ladders, etc)
6. Lower Unit
   Damage to brackets, tilt/trim?
   Foreign material trapped in water intakes?
7. Propeller
   Propeller bent, nicked, pieces missing, cavitation burn marks, or paint transfers noted?
8. Skeg
   Skeg bent, nicked, pieces missing, or paint transfers noted?
9. Windshield Frame and windshield
10. Instrument console (check for needle slap)
11. Steering wheel
12. Passenger dash area
13. Passenger windshield
14. All seats
    shifted, damaged, seat backs bent or warped?
15. Storage compartments
16. Engine compartment
17. Engine mounts shifted?
    Is there a batter box? Was battery strapped down?
18. Battery and box moved or shifted?
19. Fuel tanks shifted?
20. Under carpet near damaged hull areas
21. Hull and Deck Cap
22. Rub Rail
23. Engine Cowling (Outboards)
24. Engine cover (I/Os and inboards)
25. Speedometer transducer (pitot tube) or other externally mounted fittings
26. Thru-hull fittings
27. Window frames, perimeters of portholes for in hull mounted windows, check to see if window frames are still against the hull from outside
28. Throttle handle
29. Gearshift lever
30. Throttle cable
31. Steering cable
32. Auxiliary equipment damaged? (Depth finders, mirrors, trolling motor, boarding ladder, etc.)
33. Is steering still connected and free moving?
34. Position or presence of outboard or stern drive trim tab?
35. Trim position of outboard or stern drive

BOAT DATA CHECKLIST

General Boat Description
- Boat Model and Manufacturer
- Type of Boat (canoe, motorboat, sailboat, etc)
- Type Engine (I/O, outboard, etc)
- Hull Material
- HIN
- Year Model of Boat (and possibly of propulsion system)
- Sleeping Accommodations?

Number and type of layers of fiberglass at damaged locations

Boat Dimensions

LOA
Beam
Number of feet that max beam is from transom
Gunwale height at max beam
Transom width
Transom depth (measure parallel to transom and perpendicular to boat bottom)

Engine and Outdrive Data

Number of engines
Engine Manufacturer
Engine size (cubic inches and number of cylinders)
Engine HP rating
Engine SN
Type of Fuel Used
Power Trim and Tilt? (Trim is the first 20 degrees, tilt includes angles greater than 20 degrees)
Type Steering
Propeller Diameter
Propeller Pitch, number of blades, material
Trim Tabs on boat?
For outboards - tilt pin location

Controls Information

Throttle position
Gearshift position
Steering wheel orientation
Type of steering system
Steering system damaged? still connected?
(A disconnect at link rod is fairly common when self-locking nut is mistakenly replaced with common non-self-locking nut)
Throttle cable damaged?
Gearshift functional?
Does propeller rotate when trying to shift in reverse?

Capacity Plate Information

USCG Capacity Plate present?
Persons Capacity
Weight Capacity
Weight (persons, motor and gear for outboards)
Weight (persons and gear for I/Os and inboards)
HP Capacity (outboards only)

Instruments On board, Readings, Manufacturer or Model No.

Speedometer
Tachometer
Fuel Level
Trim - for outboard/sterndrive
Trim - for boat trim tabs
Temperature
Volt Meter

Oil Pressure
Engine Hour Meter
Record (photograph and/or video) all warning decals, or placards found throughout the boat

Other Instruments
Depth Finder
Radio
Navigation equipment

Record and Photograph All Switch Positions
blower
navigation lights
bilge pump
other instrumentation

NAVIGATION LIGHTS

Are required navigation lights still on the boat?
Combination bow light
Starboard side light
Port side light
Stern light
Masthead light
Other lights

Did you see that lights were on when you arrived at the scene?
Record witness statements regarding lights being on
Navigation light switch position
Visible damage to exterior of lights or casings

NOTE: Do not operate switches, remove bulbs or navigation lights at scene. Figure 10-1 is a copy of the chapter on navigation light examination as published in Boating Accident Investigation, 1993 by Underwriters Laboratories (Kirstein, Loeser, Morey). Refer to Figure 10-1 for procedures on examining navigation lights.

CIRCUMSTANTIAL DATA

The following data may be relevant from the standpoint of establishing the circumstances involving an accident. Many of these parameters will not apply to all accidents.

Fuel tank capacity
Approximate actual fuel level
Was boat recently serviced?
If so, what service was performed?
Did the operator have any training or boating education?
Did the operator know the rules of the road?
Did the operator see the other vessel prior to impact?
Experience of the boat operator
What was the operator's estimate of his boat's speed? of the other boat's speed?
Does the operator know if his boat was on plane, below planing speed, or somewhere in between? what about the other boat?

Was there any attempt at evasive action?
- According to the operator of either boat?
- According to occupants in the boat?
- According to witnesses on shore?
- According to witnesses on other boats?

Did anyone else see the accident?

Did anyone hear the accident?
- Was there an abrupt change in engine noise? (either due to change in throttle setting, or cavitation/ventilation)

Were other boats nearby? If yes, what direction, speed were they traveling? any passengers on board that saw anything?

10.4 The Investigator's Toolbox

During our field investigations, we made every effort to employ tools or techniques which would be available to the average investigator. Expensive and sophisticated equipment was avoided. By far the most expensive and complex piece of gear we used was a camera, and occasionally a video camera. Our equipment list was further limited to what was small enough to fit into a travel bag and would be permitted on an airplane. We quickly learned what tools the airport security guards frowned upon rather seriously. Thus, we found that with only a handful of the right tools, we could gather all of the required documentation.

A good toolkit should contain the following items:

1. camera
2. plenty of film (plan on at least two rolls per boat) (at least some 400 or higher speed film)
3. extra batteries for camera
4. two 50 or 100 ft. tape measures
5. two short tape measures (8 to 12 feet)
6. two large rolls of 1/2 inch masking tape
7. twelve inch ruler with clear markings
8. two rolls of colored tape (probably black)
9. one dozen small plastic bags (evidence bags)
10. inclinometer
11. portable stadia rod (at least 6 ft long)
12. colored water soluble markers (at least black and white)
13. 50 index cards (3 by 5 inch or self adhesive note pad)
14. silly putty or equivalent
15. accident forms, accident checklist, required paperwork
16. full size notepad of graph paper (8 1/2 by 11 inches)
17. small pocket note pad (about 4 x 6 or 3 x 5)
18. pens and pencils (black and red felt markers)
19. right triangle (30-60-90 or 45-45-90)
20. flexible curve
21. plumb bob and reel
22. protractor
23. flashlight
24. mutimeter (volt-ohm meter)
25. leather work gloves
26. safety goggles and safety shoes

The following items are considered optional but may prove beneficial:

27. Two small spring scales (0 to 25 lb range)
28. plastic damage grid
29. dictating recorder - extra cassettes, batteries
30. One roll of 1/8 inch or 1/16 inch black pinstripe tape
31. One roll of 1/8 inch or 1/16 inch white pinstripe tape
32. screwdriver set
33. hammer
34. pliers
33. inspection mirror
34. compass
35. area maps covering the accident site
36. crowbar
37. saw
38. calipers or micrometer
39. chalk line
40. magnet (check for stainless steel or aluminum vs. ferritic steels)

A few items are worthy of explanation. The portable stadia rod (item 11) is visible in many of the accident photos found in Chapter 13. It is much like a wide tape measure, except that ours had the unusual characteristic that it could stand up just like a rod when it was removed from its case. Many survey supply stores will carry such equipment. It proved to be a very useful item.

The inclinometer, (item 10) is an instrument used to determine angles from a vertical line. It is useful for measuring the deadrise and transom angle, and angles of other hull surfaces. It can also be used to determine if a boat is sitting level, either fore and aft, or side to side.

A flexible curve (item 20) is an interesting device that is incredibly useful for making drawings of boat hulls. It is about 12 inches long, and can be thought of as a flexible ruler. It will stay in roughly whatever shape it is bent, and can be used to draw curved surfaces of boat hulls with ease. It helps in making accurate on site drawings of boats. These devices can usually be ordered from office supply houses that sell drafting supplies.

A plumb bob is familiar to most people. It is nothing more than a weight and a string. The plumb bob is an essential aid when recording boat dimensions. For example, to measure the overall length on a large cruiser, the plumb bob can be used to find the spot on the ground directly beneath the bow of the boat. The same process can be repeated for the stern. The length of the boat is determined by simply measuring along the ground from one spot to the next. This process can be used to obtain other dimensions that cannot be measured directly. Reels containing string on a self retracting spool are available for use with plumb bobs and are well worth the few dollars they cost. The reel will keep your string from becoming entangled in the rest of your tool box. The reel will also keep you from spending your afternoon untying knots in your plumb bob string while you need to be recording accident data. Once

again, plumb bobs and reels are available at stores that sell survey supplies.

Work gloves and safety goggles are essential equipment. You may need to crawl into a damaged compartment, or crawl underneath a boat on a trailer to record critical data. In these situations, safety goggles are a must. Work gloves are also essential when working with badly damaged boats. Fiberglass splinters and glass fibers easily work their way into the skin and can be quite painful. Safety shoes with thick tough soles are also a must. Boats involved in collisions usually have an abundance of broken glass scattered all over everything you want to examine and every surface you need to walk on.

A damage grid is a concept borrowed from the automobile accident reconstruction community. It is typically a clear piece of material with grid lines of known spacings marked on the surface. It can be made from a clear piece of acrylic or plexiglass, or it can be made from a tough non-stretching flexible clear plastic. Since ours had to fold up and travel on an airplane, we used a piece of thick sheet plastic about two feet by eight feet. White and black tape was used to form the grid lines at known intervals of 12 inches. The purpose of a damage grid is to assist in the documentation of large complex damage patterns. The grid is placed in front of a damaged area, and then photographs are made. The material must be transparent so as not to interfere with the object photographed. The damage grid will provide a series of reference lines a known distance apart that will firmly establish the scale of the area involved. Scale drawings, models, or other re-creations of the damaged area may then be constructed much more easily by using a photos where damage grid was used.

The chalk line may be useful for creating a straight fixed reference line on a large boat with few natural reference surfaces from which to measure.

10.5 The Accident Scene

10.5.1 Importance of the Accident Scene

The accident scene may play an important role when reconstructing an accident. Its importance should at least be considered. Understanding the area in which an accident occurred can help to provide insight into the overall sequence of events leading up to an accident. For example, two boats which collided head-on near a peninsula may not have been able to see each other in time if they each came around opposite sides simultaneously. It is important to draw a scale diagram of the accident scene area. Area maps can be utilized as the basis for constructing scene diagrams. Keep in mind that various marine templates are available which contain common boat shapes and many marine symbols that may help to construct scene diagrams.

The accident scene is important in CWFXO and CWFLO accidents because it can be valuable to examine the object struck. In the cases where a submerged or barely visible object was struck, the object should at least be marked so future accidents can be avoided. It is also possible that by assessing damage to the struck object, additional information regarding relative speed and severity of impact can be determined. In CWAV accidents, the big question is how does one go about determining where the accident site was? After all, you really cannot locate the skid marks on the water!

Locating an accident scene may be important because much of the evidence needed for a reconstruction may be on the bottom directly underneath the impact site. Large hull sections, and occasionally an entire boat, will be sunk after an accident. Locating the missing pieces may provide critical data to assist with the reconstruction. In an over-ride accident, the hull section of the target boat which suffered the initial impact may be lying on the bottom.

10.5.2 Methods for Locating an Accident Site for CWAV

This is one area where witnesses can be valuable. Without witness statements, it may be impossible to locate the area where an accident took place. Even without witness statements, a few common sense guidelines may help. We will briefly summarize a few techniques used by various investigators in the past to successfully locate an accident site.

After a collision, varying amounts of debris are usually floating in the water nearby. This debris will be carried away from the accident site by wind and currents. One method for estimating the location of the accident site is summarized below.

The Floating Debris Method for Impact Site Determination

1. When you arrive in the accident area, look for floating debris.
2. Record the time when the debris is spotted.
3. Calculate the time which has elapsed since the accident occurred. This is how long the debris has been drifting.
4. Note the current direction and speed at which the debris is drifting.
5. Record how far the debris moves in a given time interval, such as ten minutes or longer depending on how fast the debris is moving. Obviously, this step will require some ingenuity. One possible method is to anchor your boat ahead of some drifting debris and measure the time for the debris to travel the known length of your hull.
6. Assuming that the debris has been moving at a constant speed and direction since the accident occurred, estimate the distance the debris was from the accident site when you located it.

7. Travel in the direction opposite that which the debris was drifting for the distance calculated in step 6.
8. You should now be in the approximate area of impact.

The above method is subject to many errors and variables. The quicker the investigator arrives on the scene, the more likely the suggested method will work. It will probably give meaningful results only within the first few hours after an accident, if that long.

Another method for locating the accident site requires the use of highly sensitive depth finders to look for large debris. This technique has been used effectively to locate sunken boats after an accident. Diving to locate debris is also an alternative; however, more often than not, the limited visibility in most lakes and rivers prevents it from being practical.

It is worth mentioning that many investigators have commented that even in lakes and streams with relatively strong currents, most sinking debris seems to settle directly beneath the impact point. The debris field is commonly found within an area of a radius not more than two times the water depth.

10.6 Practical Photography

Photographs provide an important part of the documentation of an accident. Photographs must be taken properly, or their value is greatly reduced. We have already discussed what to look for and where to find it. Now it is time to focus on how to photograph it so that after the photographs are developed, you will still know what you are looking at!

Instead of teaching basic photography, we will concentrate on techniques which were developed to enhance the value of the photographs taken. These guidelines were developed during the field investigations we conducted.

1. Always include a measuring reference in each photograph. Judging distances and lengths of objects in photographs is subjective unless a scale is visible in the photograph. The scale may be a ruler, a tape measure, damage grid, or portable stadia rod.

2. Make sure that the orientation of the photo is clear. It can be difficult when taking a close up photograph to know which direction is up or which direction is forward. Every photo that does not include enough of the overall view of the boat to determine the orientation of the photograph must include some type of orientation notation. An orientation mark may be an arrow with an F (for forward) written in magic marker in the area being photographed. It may also appear on an index card taped to the surface, or on a self sticking page from a notepad. Notations as to the forward or aft direction,

port or starboard direction, or even up and down directions should be indicated as appropriate.

3. Always know where on the boat the photographed area is located. This applies to close ups as well as any photos where the location needs to be clearly specified. At least two measurements are usually required to document a location. The longitudinal and lateral coordinates of the area are required, and must be referenced to a known location. By this we mean that referenced locations should be carefully chosen and should be fixed points which can be easily measured. For example, a gouge in the side of the hull may be marked as being 96 inches from the stern and 14 inches beneath the center of the rub rail. As long as you have measurements that document where the rub rail and the stern are located, these measurements will positively document the location being photographed. It should be noted that for some areas, a vertical reference measurement may also be required. Several methods exist for documenting the coordinates of a photograph. The point being photographed can be assigned a number or letter for reference, which should be visible in the photograph. The number or letter assigned can then be shown on a diagram of the boat's damage. It is also generally feasible to write the coordinates down using either index cards taped to the hull, self adhesive note paper, or washable magic marker. If the latter method is used, the coordinates should be visible and legible in the photograph. Drawing a diagram with the coordinates of each photograph or designated area noted is useful, especially if something happens and your photographs do not develop properly. If you have a diagram, you still have enough information to possibly reconstruct an accident.

4. Do not use a wide angle lens if you intend to scale distances from a photo. Wide angle lenses distort the field of view to the point where making scaled measurements from a photo is not possible.

5. Take photographs at right angles to the surface when possible. This makes scaling distances from striations or other parts of the photo much easier and more accurate.

6 If a damage grid is used, take photographs of the area both with and without the damage grid in place. Depending upon the material chosen for a damage grid, details of the damage may be slightly obscured when viewed on a photograph. When taking photos of the area without a damage grid, a scale of reference should still be used.

7. Highlight striations that are too light to show up in a photo. Use the techniques discussed in section 10.3.1 to make sure that striations are visible in the photograph. If there is doubt regarding their visibility, photos can

be taken without enhancement first, followed by photos with the striations enhanced.

8. Be sure to label rolls of film immediately upon removal from your camera!

9. Try to plan your photos so that photos of only one boat, or one main subject are on each roll. If you have a series of close up photographs of both boats on the same roll of film, the chances of getting the photos mixed up are greater than if only one boat is on each roll.

10. If you are about to disturb something, be sure to photograph it before you move it.

11. You may want to consider taking a photo with and without a flash. Taking the same shot with and without a flash often brings out some detail with one method more so than the other.

12. Consider using a camera which prints the date on the photograph.

The above guidelines may not always fit your particular situation, but following these guidelines will help to make the information in the photographs much more valuable when conducting a reconstruction. The proper photos combined with appropriate damage diagrams provide excellent documentation of the damage on a boat.

10.7 Damage Matching

When two boats collide, each boat leaves damage behind on the other that often indicates which parts of the boats were in contact. The damage done to a certain area of a boat looks the way it does because of the shape, hardness, and other characteristics of the object which struck that area. It is often possible to determine what particular object or area of another vessel created certain damage. As an example, a series of parallel cuts in a windshield frame is an indication that the propeller of another boat passed through that area. Unique striation marks, imprints, and material transfers often reveal the specific object which struck that area. Determining what object or which specific part of another boat created a certain damage pattern is called damage matching.

Damage matching is important because it helps to determine the orientation of the two boats while they were in contact during some part of the collision process. Techniques for damage matching vary depending upon the particular damage being analyzed. Types of damage that usually lend themselves to being successful candidates for damage matching usually have certain characteristics. When attempting to locate damaged areas where damage matching should be attempted, look for these signs:

a. Paint transfers - When two surfaces contact each other, they may swap portions of paint. The color of the paint left behind on a surface is especially important when the paint transferred is a color found on only a small part of the other boat. Decals are excellent candidates for damage matching because they often contain colors that are not found on other parts of the boat.

b. Deep Parallel Scratches - Usually deep striations in the fiberglass hull of a boat are caused by rubbing against a metal object on the other boat. The depth and distance between the striations can be helpful in isolating the specific object.

c. Gouges - Gouge marks, or deep digs in a fiberglass hull, especially when found in the chines or the bottom of the vee of the hull, may be caused by striking an object such as a deck cleat or hand rail. The approximate size and shape of the gouges should help to locate the object which created these marks.

d. Imprints - Imprints may be hard to recognize, and once located, it can be difficult to determine the object responsible for the imprint. Many imprints are only partial in nature, and have the outline of an object only on the leading edge of the imprint. The trailing edge of the imprint may be smears and striations. Even these patterns make good candidates for damage matching.

e. Dents or Bends in Metal Surfaces - If a handrail, windshield frame, or other metal surface contains dents, or unique bends, it may be possible to match it to the surface which struck it. Propeller marks and skeg marks across metal surfaces are often easily identified. Scratches or bends to the propeller are usually visible if the propeller struck a metal object. If the propeller was constructed of stainless steel, most or all of the damage may be on the struck surface, even if the struck surface is metal.

Many examples of damage matching are discussed in the field accident reports in Chapter 13. Several techniques can assist with damage matching. When attempting to match a fairly small damage pattern to an object, it may be helpful to make a full scale diagram of the damaged area. For example, a transparency could be laid over a series of striations, and the striations or gouge outline could be drawn. Then, with transparency in hand, the other boat can be examined for an object which might have made those marks.

Using modeling clay or certain types of putty to fill in a dent in a metal surface, and then walking around the other boat to locate an object the approximate shape of the putty can assist in locating the object which caused the damage. If it is desired to make a permanent cast of a dent or damage pattern, several options

are available. Plaster of paris can be used to make a cast. Some success has been reported with using dentist's clay. This is the clay that dentist use to make molds of an individuals teeth for study. The detail retained by this technique has been reported to be excellent.

A scale damage diagram can be helpful in evaluating the feasibility that an object could or could not have struck the area in question. Examples of such diagrams are found in Chapter 13.

10.8 Procedures For Documenting Damage On A Boat

Arriving on the scene of a bad collision can be an humbling experience. In a CWAV accident, the struck boat may be so mangled that one hardly knows where to start. Following established guidelines in such situations will help to minimize the chances of losing valuable evidence and will make the most of the time available for documenting the accident data.

The guidelines presented in this section are intended for severe accidents where a reconstruction is definitely going to be needed. These procedures are extensive, and may require quite some time to complete. Two investigators working together may be able to complete the task presented in only a few hours.

What is the goal of the ultimate documentation procedures? If damage and critical items were documented perfectly, we would have sufficient information to construct an accurate three dimensional scale model with all the key damage points in the correct places. We could construct perfectly accurate diagrams to scale containing boat dimensions and damage locations. In short, we would have everything we needed to begin to conduct a reconstruction of an accident. When critical damage is documented, it should be done so precisely that the same spot could be located on an identical boat with near perfect accuracy.

10.8.1 First Steps- At Scene Guidelines

Once critical responsibilities related to life and safety are addressed, the job of documenting the accident may begin. The first step toward documenting data at the scene is to get an initial set of photographs as soon as possible before anything is disturbed. If everything is already disturbed, go ahead and take photographs so that you at least have a record of how things appeared as soon as you arrived on the scene. If the boats are still in the water, go ahead and take photographs. Even if it is dark and you are not sure that your photographs will come out, go ahead and take some of the initial scene.

This initial set of photographs will vary depending upon the situation at hand. Below is a short list of items to cover:

- The accident scene as you find it
- Both boats, or the boat and the object struck
- Photos of the boats should include:
  - overall views
  - victim locations
  - any debris on shore or found nearby
  - steering wheel, instruments, and other items as appropriate on the checklist in section 10.3.4
  - navigation lights (for night time accidents)
  - location of throttle/shift levers and linkages
  - location of engine trim or boat trim tabs

The primary purpose of the initial set of photos is to document how things are as you found them. This data will most likely be the data documented closest to the time of the accident, giving it more credibility than photos taken several days later.

It is usually advisable to take the very first photographs before disturbing anything. Thus, these photographs will not contain a fixed scale reference. Even placing rulers, tape measures, or other instruments on a boat may leave questions in other's minds as to whether the accident scene had been disturbed by the investigator before the photographs were taken. Philosophies differ on this point, and you might find it acceptable in your situation to proceed with placing scale references in the desired areas before the first photographs are taken. This may be especially true if you have limited time, film, or daylight left in which to work! Remember that photos without scale references are not usually as valuable when constructing diagrams and conducting a reconstruction later. If the initial photos are taken without scale references, it is generally desirable to repeat certain critical photos at the scene with the scale references in place. Try to document items that may help to distinguish collision damage from rescue or salvage damage. Are both boats just pulled up onto a concrete or gravel boat ramp? If so, then be sure your initial photos show this. Photograph the area where the boats are sitting, and show the marks left in the ground where the boats were drug up onto the shore. Boats which have been beached should have striation marks on the hull bottom. Of course you must keep in mind that many recreational boats are beached as a routine manner and may have hulls full of scratches not relating to the accident. Keeping records of all activities that involved the boat following the accident will help you separate accident damage from boat recovery damage.

10.8.2 Boat Preparation

Once the initial photos are completed which show clearly all the critical information as you first found it, you can proceed to more detailed documentation procedures. Before we can go too far, we must prepare the boat to maximize the data we can easily obtain from our documentation procedures. The following steps outline a set of common preparation procedures that will make it easier to record data from the boat.

1. Place the boat in a good location-
Try to have the boat in a location with good light, on a level surface, and preferably on a trailer or cradle. (Not sitting on the ground). Use your inclinometer to be sure that the boat is level on the trailer, and that the horizontal longitudinal centerline of the boat is parallel with the ground.

2. Establish a horizontal reference line-
Take a long tape measure (preferably a wide one with large numbers) and place it along the top edge of the rub rail of the boat so that the zero is in line with the aft corner where the transom meets the hull side. Note that the tape measure may be placed along a deck, or along a horizontal reference such as the waterline, or a chalk line you created. The tape measure should follow a horizontal reference line from bow to stern. For some boats the rub rail may serve as an adequate reference point, though rub rails are not always in a straight line or horizontal. For sake of illustration, we will assume for the rest of this exercise that we have a boat with a horizontal rub rail.

3. Enhance the visibility of the horizontal reference line-
Place tape of a contrasting color of a known length (probably 12 inches or 24 inches) vertically every two feet along your horizontal tape measure. The tape will show up well even when you no longer can read the numbers on the tape measure. The tape can also be used to hold the tape measure in place.

4. Repeat steps 2 and 3 for the opposite side of the boat-
You should do this even if the opposite side of the boat is not damaged. You may wish to know how far something is from the front on one side that is missing on the other completely. For example, if you know that the handrail next to the passengers seat was struck by the bow of the boat, and it is has been broken from its mounts, the handrail on the other side of the boat can serve as a guide as to where the broken one was mounted.

5. Establish a horizontal reference on the stern-
Take a small tape measure and lay it along the top edge of the rub rail across the stern. The zero reference should be at the port side, placed evenly with the corner where the stern meets the side of the hull. It should also meet the tape measures on the two sides of the hull. For outboard powered boats, it may be necessary to place the tape measure on the transom even with the lowest point of the outboard motor-well. The tape should be run in front of the outboard motor and be placed against the transom surface to the extent possible.

6. Enhance the visibility of the stern reference-
Repeat step 3 for the stern. The tape will be useful here as well. Now you are ready to start recording data.

10.8.3 Documenting The Boat Data

Once the boat has been fitted with tape measures for reference, the basic hull shape must be documented. After the hull shape is documented, then details regarding damage and specific photographs can be made. The following steps pick up where those in the previous section left off.

7. Obtain the critical measurements of the boat's dimensions-
   The diagram in Figure 10-2 contains a diagram of the dimensions necessary to re-create a hull shape with a reasonable degree of accuracy. Obtain these dimensions. If the boat which you are documenting does not relate to this diagram, create your own list of required dimensions that will be necessary for you to create accurate drawings later.

8. Create the overall diagram-
   At this point, if time permits, it is best to go ahead and draw a scale diagram of the views of the boat which you need in order to document your damage. For obvious reasons, you should do this in pencil. Use the ruler, triangle and flexible curve to draw a scale diagram on your graph paper. Generally you will want a top view and possibly a side view. Top views are most useful for determining impact angles in over-ride collisions. By creating the drawings while you are with the boat, you can determine any additional dimensions needed to complete your diagram.

9. Take photographs of damage-
   In most cases, the best procedure is to start at the bow on the outside and work your way around the boat. Once you have gone all the way around the perimeter, you can then go to the bottom of the hull. Finally, go to the inside of the boat to photograph damage there.

10. Take critical photographs containing relevant information-
    Use the checklist in section 10.3.4 to remind you of areas that you should examine and consider photographing. This list contains many items that do not necessarily relate to damage. You should at least look at the checklist and take those photos which apply to your situation. Remember to use the procedures discussed in earlier sections of the chapter when taking photographs. You should also remember that it can be just as important to have photographs of key parts of a boat which have not been damaged.

11. Add the damage observed to the diagram-
    You should have completed the sketch of the boat that is approximately to scale, and recorded basic measurements that document the hull shape. Now it is time to add

notes to the diagram in the appropriate locations regarding the damage found on the boat. Examples of damage diagrams may be found in Chapter 13.

12. Document the condition of navigation lights- Obviously this applies primarily to night time accidents. A procedure for examining the condition of the navigation lights was developed for the Boating Accident Investigation Seminars, sponsored by a grant from the USCG. These procedures are contained in Figure 10-2, and provide guidelines required to help determine if the navigation lights were on or off at the time of the accident. Refer to the list of references for additional information.

Since many of the small lamps used in boat navigation lights are of similar construction to those used in certain types of automobile lights (except for headlights), much of the material developed for examination of lamps used in automobiles applies to boat navigation lights as well. The reader is referred to The Traffic Accident Investigation Manual, Volume 1, which contains the best information we have located, to date, on this subject. Additional information may also be found in the Marine Accident Investigation Manual, which was developed and published by Underwriters Laboratories under a USCG sponsored grant.

Some references have suggested that filament deformation when the light is on can be used as an indication of the direction of impact. Some texts on auto accident reconstruction recommend against this practice as they have found that the filament will react to local accelerations only, which may be misleading when attempting to determine angle of impacts. The filaments may also be subject to shock forces of rebound, which can distort the filament in directions not related to the direction of impact. In short, it is acceptable to use stretched filaments as an indication that the lamps were on at the time of the accident, but not as an indication of impact direction.

10.9 A Few Notes On Measurement Techniques

A quick review of the suggested dimensions in Figure 10-2 will raise questions in the mind of the investigator as to how to obtain some of those measurements. Many measurements, such as overall length, beam, and others are best made by using a plumb bob and a tape measure. This method works for measuring overall lengths, distances between chines, and beam dimensions. Use the plumb bob to mark a spot on the ground directly beneath the measuring points. Then use a tape measure to determine the distance between the two points along the ground.

The tape measures placed along the side of the hull at the rub rail provide an accurate and quick reference as to how far an object is from the stern for most of the length of the boat. When documenting a boat's dimensions, or the location of a an object,

the photo should clearly show the measurements on the tape measure placed next to the rub rail. Figure 13-48 shows a profile view of a boat with the tape measure placed just above the rub rail. Vertical stripes of masking tape are placed two feet apart, and are used to hold the tape measure in place. For overall views, even though the numbers on the tape measure are not legible, the vertical tape stripes can be clearly seen and serve as a guide for estimating distances. When taking close up photos of damaged areas near the rub rail, the numbers on the tape measure should be recorded in the photo so that the position can be easily located on a boat damage diagram. When the beginning of the tape measure is placed at the stern, the numbers on the tape measure can be used to estimate the distance the location being viewed is from the stern. When the bow begins to curve inward, the tape measure no longer reflects an accurate linear distance to the stern, but it is still a good approximation for most boats. Even so, the numbers on the tape measure should still be recorded for reference.

The following illustrates how to correlate the numbers on the forward part of the tape measure which are near the bow of a boat to a scale damage diagram of the boat. The distances on the tape measure near the front of the boat can be useful because they can be placed on a boat damage diagram with reasonable accuracy. Be sure that you record the reading on the tape measure where it reaches the forward most part of the boat. Figure 13-65 shows the tape measure in position at the bow of a ski boat. The tape measure shows 20 feet, 10 inches at the forward most part of the bow. These numbers can be helpful when constructing a scale damage diagram. Draw your diagram to scale of the top view of the boat, making certain that the curvature of the hull passes through the proper points. Generally, the transom width, the maximum beam, the beam at the chine termination (CT), and one intermediate point half way between the CT and the maximum beam will be adequate to draw the hull curvature. Use the flexible curve to connect these points. Now place the zero end of the flexible curve at the stern, and let it lie on top of the curve you just drew that represents the perimeter of the hull. The scale markings on the flexible curve should now be consistent with the numbers which appeared on the tape measure all along the side. In the boat shown in Figure 13-65, the scale on the flexible curve should correlate with the numbers on the actual tape measure.

Measuring hull angles can be important when drawing diagrams from the front view of the boat. These are the angles that the hull sides are from the vertical. Refer to measurements 3F, 5B, 4A, and 6E in Figure 10-2b for clarification. To measure these angles with a clinometer, place the edge of the clinometer against the hull side, but make sure that the plane of the clinometer is parallel with the transom (or perpendicular to the centerline) of the boat. This will give the angle of the hull side in the lateral plane, which is the angle needed when drawing the front views of the boat.

It is worthwhile to comment on a few of the points mentioned in the diagram in Figure 10-2. We will address them by the numbers

as shown in the figure. First, the explanation of a few terms would be helpful.

RRC: rub rail center. This serves as a common reference point for many measurements. Measuring from the center of the rub rail eliminates the guesswork of trying to remember if you should always measure from the top or the bottom of the rub rail.

Note that if the rub rail is not essentially straight, then you must do one of two things. You can either take measurements between the rub rail and the horizontal level surface that the boat is sitting on to determine the curvature of the rub rail, or you can use a chalk line to create another reference from which to measure.

CT: chine termination. On most boats, if you follow the chines forward, the lines of the chines disappear and blend into the bow a short distance from the end of the bow. We call this point the chine termination. It serves as a useful reference point on the boat from which to make the measurements shown on the diagram.

SUGGESTED DIMENSIONS FOR DOCUMENTING A BOAT SHAPE (Figure 10-2)

1: Overall length not including appendages
1A: Measurement of the extension which includes the bow pulpit
1B: Measurement of the extension which includes the swim platform

2: Transom width at rub rail

3A: Maximum beam, probably occurs between opposite RRCs
3B: Beam at the chines, measured directly below the maximum beam
3C: Distance from stern where maximum beam occurs

Note: For some boats, such as bass boats, the maximum beam may be at or very near the transom. If this is the case, the measurements for 3A, 3B, and 3C will be very near the stern. If this happens, then another set of similar measurements should be made at half the boat length to help complete your diagram on hull shape.

3D: RRC to chine, useful in determining the chine profile
3E: RRC to hull bottom. This measurement can not be made directly. One method is to obtain this dimension is by measuring the distance from the RRC to the ground, and then subtracting the distance from the hull bottom (at the center) to the ground.

3F: The angle of the hull sides from the vertical. Use your clinometer to obtain this measurement.

4X: Bow to CT (distance from the bow to the chine termination). Again, you may need to use a plumb bob and make a mark on the ground directly beneath each point, then measure the distance between these points.
4Y: Beam at CT
4Z: Vertical distance from RRC to CT
4A: Angle at the CT of the hull side
5X: Distance from stern to the Intermediate Point (IP)
5Y: Beam at IP (usually measured at rub rail)
5Z: RRC to Chine
5A: RRC to Hull Bottom (at center) Use same technique as for 3E.
5B: Hull angle at point 5 (the intermediate point)
5C: Distance between chines at point 5 (the intermediate point)

The Intermediate Point (IP) on a boat is intended to provide a set of measurements approximately half way between the maximum beam, and the CT. This point may be the point at where the sides really begin to turn inward toward the bow.

One method for determining where the sides begin to turn toward the bow is to have one investigator stand near the transom and sight along the rub rail. Have a second person hold an object about an inch wide against the rub rail, beginning at the maximum beam. Have the second person slide the object along the rub rail forward. The investigator at the rear of the boat should signal when the object disappears from view. The distance that the object is from the stern when the object disappeared from view should be recorded. This technique is designed to help estimate when the bow has curved in a certain distance.

6A: RRC to chine at the hull side aft end
6B: RRC to hull bottom (use technique for 3E)
6C: Hull bottom to skeg bottom (with outdrive/outboard lowered to pre-impact position, and possibly fully lowered)
6D: Chine to chine distance
6E: Hull angle at transom (deadrise)
6F: RRC to top of swim platform
6G: RRC to top of deck cap at stern

(Even though not on this list, be sure to record propeller diameter and pitch.)

7A: Stern to leading edge of windshield (WS), measured at center (single or dual console boats with no center windshield need console and WS locations recorded)
7B: Stern to top of WS, measured at center
7C: WS top to RRC, measured at center
7D: WS top to RRC, measured at side frame
7E: Back of side frame of WS from stern
7F: Bottom of WS side frame to RRC at forward edge of WS
7G: Bottom of WS side frame to RRC at aft edge of WS

Note: 7C is a tricky measurement and is important if the top

surfaces of the windshield were damaged in an accident, or if an over-ride has occurred and it is possible that the other boat jumped over these surfaces. The measurement can be made with a straight rod or board, a level, and a tape measure. Make certain the boat is level. Place the rod across the windshield's highest point, perpendicular to the boat's longitudinal centerline. Place a level on top of the rod and adjust the rod until it is level. Measure from the RRC to the bottom of the rod. You may wish to use a plumb bob to assist in the last step. This measurement requires at least two and possibly three people to be done correctly!

8A: Deadrise angle at the bow, measured with an inclinometer, taken at the CT.
8B: Transom angle, taken at the center of the stern below the RRC

Additional measurements: Additional measurements will need to be made to document other important features as they apply to the boat being examined. This diagram is intended to provide you with ideas about the types of measurements required to create a scale drawing of a boat hull with a reasonable degree of accuracy.

10.10 Summary

Once the procedures in the previous section have been completed, the photographs should be developed immediately. Ideally, the boats should be retained until you are certain that you have all the data required for your reconstruction.

CHAPTER 14

NAVIGATION LIGHTS

When a collision occurs between sunset and sunrise, or under conditions of poor visibility, the investigation should always include a determination of whether or not the navigation lights were being used on either or both boats. If the lights were functioning, and if their use may have been a contributing factor, then there are still a number of facts that must be investigated. In some cases, it may be necessary to have the lights tested in a properly equipped photometric dark tunnel to determine if they comply with the "International Regulations for Preventing Collisions at Sea," (72 Colregs - COMDTINST M16672.2B) or, for small pleasure boats, the American Boat and Yacht Counsel Standard No. A16.

If it becomes necessary to send the lights to a laboratory for testing, the tests for both commercial vessel lights and small boat lights can be conducted in accordance with ANSI/UL 1104. In most instances, laboratory testing would be limited to a check of light intensity (range of visibility), cut-off angles and possibly chromaticity.

When conducting a navigation light examination remember one fact DO NOT TURN THE LIGHTS ON. As explained later, if the glass of the lamp cracked as a result of the collision, turning the lights on will cause the filament to blow - destroying critical evidence!

Like any other investigation, navigation light investigations must be systematic. The following step-by-step case procedure describes a proven investigation sequence.

I. NAVIGATION LIGHT CASE PROCEDURE NIGHTTIME COLLISIONS

A. Equipment Needed

1. Sketch pad, accident forms, interview forms, accident template, pens
2. Camera - Standard lens, black and white or color film
3. Cassette recorder and cassettes
4. Multimeter and extension lead

B. Personal Safety Considerations After A Collision

1. Vessel instability after collision
2. Hazards from vessel recovery, equipment recovery
3. Possible electrical shorts, battery spills
4. Sharp objects

C. On Scene Procedure

After all safety concerns and other official duties have been implemented (i.e., securing scene--do not allow removal of <u>any</u> evidence):

1. Locate and identify all occupants and witnesses (tape record interviews if possible).

    a. Name, address, phone number.

Figure 10-1 (page 1)

From Boating Accident Investigation, 1993

2. Interview occupants (use tape recorder).

   a. Record narrative of events.
   b. Ask about navigation lights after narrative (don't lead the witness).
   c. Determine each occupants location on the boat prior to accident. Include their locations on your sketch. Did their locations obstruct the navigation light?
   d. Determine what portable equipment was on board prior to the accident and determine its location (i.e., cooler, extra battery, shotguns, tackle boxes, etc.). Include their locations on the sketch.
   e. Determine if alcohol or drugs were involved. This may have altered the witnesses perception of the lights.
   f. Record the occupant's opinion of weather conditions, sea conditions, time, and whether or not any land masses, tress or lights along the shore affected visibility of the navigation lights.

3. Interview witnesses

   a. Determine their location in relation to the accident. Include on sketch.
   b. Determine the boats' speed, direction, and location.
   c. What was their opinion of weather conditions, etc.
   d. How do they describe the occupant locations.
   e. Record a narrative of events. Ask about navigation lights after the general narrative. Don't lead the witness.
   f. Determine if the witnesses or operator are color blind and if there is any form of vision impairment.
   g. Show the operator a picture of a red light or green light and ask which direction the boat is moving. If the operator saw only a white light what does that tell the operator.

4. (Attempt to) Locate the scene of the accident.

   a. Survey the surrounding area for equipment, floating debris, beer cans, etc. Show their location on the sketch of scene.
   b. Take photographs.
   c. Record a description of the scene, perhaps on a tape recorder, video recorder or in simple notes or sketches. It is important to visit the scene at or near the same time of night to observe background lighting. In general, would the navigation lights tend to blend with the shore side lights. You might even visit the scene on the same day of the week since many locals have different patterns of activity on weekends versus weekdays.

5. Recover the vessel and equipment.

   a. Record the floating attitude of the boat. Take a photo if possible. Since the navigation lights might be accidently

Figure 10-1 (page 2)

From Boating Accident Investigation, 1993

damaged during recovery we highly recommend photographing or video recording the boat prior to and during the recovery operation.

6. Record the vessel information and take an inventory using notes, recorder, photos, sketches.

   a. This is general information needed for your report.

7. Examine the vessel.

   a. Sketch and photograph the vessel to show any obstructions that block the lights or to show if the method of installation affects visibility. The visibility must be checked for a full 360 degrees horizontally and plus or minus 7 degrees vertically. Determine the visibility when the boat is in the operating plane it was in at the time of the accident (i.e. bow up, down, level). If the boat was hit from astern and the stern light was improperly mounted in the transom with the outboard engine mounted on a bracket aft of the light, the light will not be visible from directly astern. On some boats the combination bow light is partially obscured by a bow rail or coil of rope. In the case of separate red and green bow lights the lights are sometimes mounted in the curved section of the bow and may be several degrees out of line. In this case, from straight ahead or several degrees off center both the red and green lights may be visible.
   b. Document the light switch position. It may have been altered by the collision or purposefully. TAKE A PHOTO. DO NOT ALTER THE SWITCH POSITION! But remember that the switches may have been changed after the accident.
   c. Examine the area around the navigation light fixture. (DO NOT REMOVE THE LIGHT YET.) Look for any indication occupant may have obstructed its view (e.g., blood stains, torn clothing, etc.). See if the navigation light fixture is even present (e.g., broken light pole still in socket, etc.). Take a photo.
   d. Visually examine the navigation lights. DO NOT REMOVE THEM YET! Is the lens cracked? Is there a sock over the light? Is the lens fogged or has the lens changed color due to ultraviolet light?
   e. Visually examine all navigation light wiring, connections and the fuse, but do not alter the connections. Analyze the circuit to determine if it is properly wired. Look for broken connections, corrosion, etc. Take photographs. You may be able to skip this step if you are going to conduct a circuit analysis. NOTE - The fuse may be blown by a short circuit caused by the collision. Determine by visual observation if the fuse blew from a short or an overload as discussed in Chapter 10.

Figure 10-1 (page 3)

From Boating Accident Investigation, 1993

8. Conduct Circuit Analysis

a. Check the voltage source.

i. If the collision involved an anchored boat, or a barge, the navigation lights were most probably operating strictly off the boat batteries. The lower the voltage, the lower the light intensity and the lower the range of visibility. The voltage underway should read 13 to 14 volts dc. But will quickly fall below 12 volts when not underway. To determine the voltage (approximate), determine from witness interviews how long the lights were operating after the engine was shut down and conduct a test using the same battery.

ii. If the boat engine was running, the lights are operated off the engine dc generator (alternator). Was the generator operating properly? You might rely on the operators/owners statements or conduct a simple check to check, start the engine and test for the voltage at the battery terminals it should normally be 13 to 14 volts for a 12 volt system.

b. Conduct Circuit Analysis

The method of testing a navigation light circuit will depend on what was done before you arrive at the scene. If nothing has been touched and the circuit switch is off, a Circuit Continuity Test should be Step 1. If the navigation switch is already on then you can use either continuity or voltage. If the lights are burning you know there is continuity but you do not know the voltage at the lamps.

c. Continuity Test

In order to check continuity it is necessary to find the conductors to the bow light, the stern light and the anchor light at the panelboard. There are different methods of wiring the lights and Figure 14.1 shows two examples. In the system where the stern running light is used as an anchor light, it should be possible to check both lights without disconnecting any wires. With the double switch in the off position, a Continuity Test would be conducted from the switch contact to the grounded terminal strip. If the wires and filament are good, the meter will show "continuity". It will actually read the resistance of the two wires plus the lamp filament resistance.

When this test is conducted you must be sure you are only reading the wires to a single lamp. In the alternate circuit shown in Figure 14.1, you would be reading two lights (bow and stern) unless you disconnect one wire at switch terminal A (alternate circuit).

Figure 10-1 (page 4)

From Boating Accident Investigation, 1993

In this Continuity Test, if the circuit shows any open circuit, the continuity of the circuit is most likely open at:

- i. Corroded connection(s) at plug-in connections at B (stern or bow)
- ii. An open lamp filament
- iii. Broken wire
- iv. Bad lamp contact at C

9. Conduct A Lamp Examination
   - a. Remove the lens cover from the lamp.
   - b. Mark the lamp and base with a permanent marker so that the lamp can be replaced in the same position.
   - c. Examine the base of the fixture for information concerning the type of bulb that it requires. Then record type of bulb used. If they are different, the light may have been on but will not necessarily have sufficient candlepower.
   - d. Examine lamp per the following section. Look for the following:
     - (1) filament - bending, breaks, detachment from support, melting or tapering of break ends, sharpness on break ends, discoloration such as blackening or whitening, direction of stretching, may assist in determining the direction of impact. Do a continuity check.
     - (2) filament supports - bending, breaks, rusting, discoloration, etc.
     - (3) glass envelope - glass envelope - white color may indicate that the glass was broken before light was turned on. Blackening is usually due to age.
     - (4) Base - damage, corrosion, dirt, etc.

NOTE 1: Unless you are absolutely confident in your ability to analyze the lamp, send the lamp, base and fixture as one unit to a crime lab for examination by lamp examination experts.

NOTE 2: After you have conducted the lamp examination and determined that the light is operational, now you may turn the lights on to check for range of visibility, and cut off angles (check the 1972 COLREGS).

II. <u>LAMPS</u>

Based on investigation techniques developed in the automotive field, it is sometimes possible to determine if a lamp was on or off when broken, and therefore, if it were burning prior to the collision. However, it must be stated that some of the indicators will only occur if the navigation light (or other light) was physically very close to the point of impact.

Figure 10-1 (page 5)

From Boating Accident Investigation, 1993

FIGURE 14.1

TYPICAL NAVIGATION LIGHT CIRCUITS

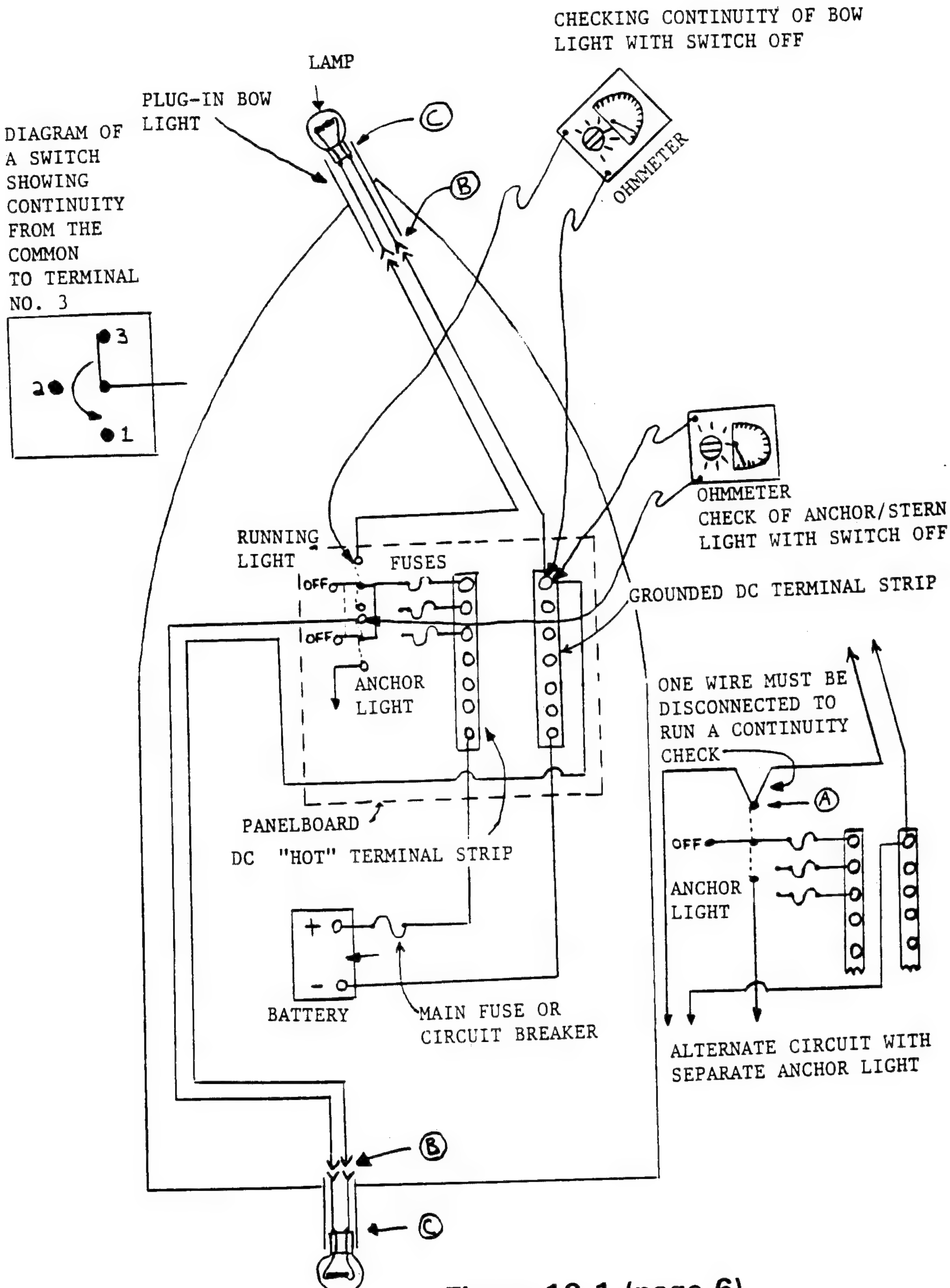


Figure 10-1 (page 6)

From Boating Accident Investigation, 1993

A. **Filament Types**

There are many types of filaments used in navigation lights and some types leave better indicators than others. Figure 14.2 shows four configurations. As indicated, the tungsten filament is normally wound in the form of a helix and the diameter and length will depend on the lamp voltage and wattage. In a new lamp, the helix is very evenly spaced and is supported by support wires.

FIGURE 14.2

FILAMENT TYPES

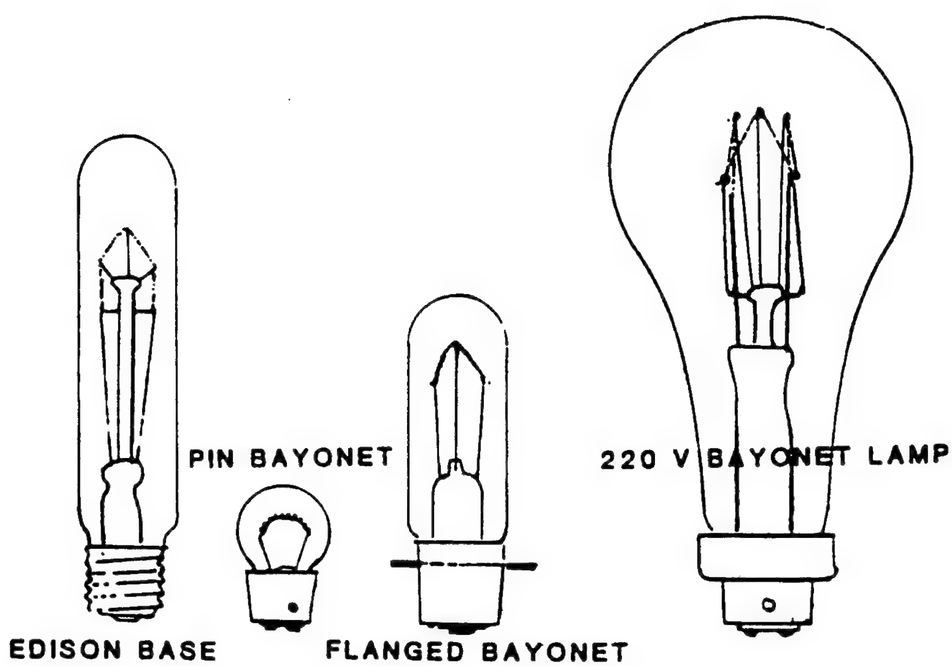


Figure 10-1 (page 7)

From Boating Accident Investigation, 1993

B. **Filament Breaks**

1. Lights Off - If a collision occurs and the navigation lights were off when the filament breaks, the break will be a mechanical fracture and the broken ends will be sharp. The filament helix will normally remain evenly spaced.

2. Lights On - If a lamp filament breaks when the light is on when the filament is white hot, the temperature softens the tungsten and the stress caused by the collision impact may distort the filament helix before it breaks. When the filament breaks, a blob of metal will normally be formed on at least one of the broken ends and neither end will be sharp. See Figure 14.3 showing various filament break patterns.

FIGURE 14.3

FILAMENT BREAK PATTERNS

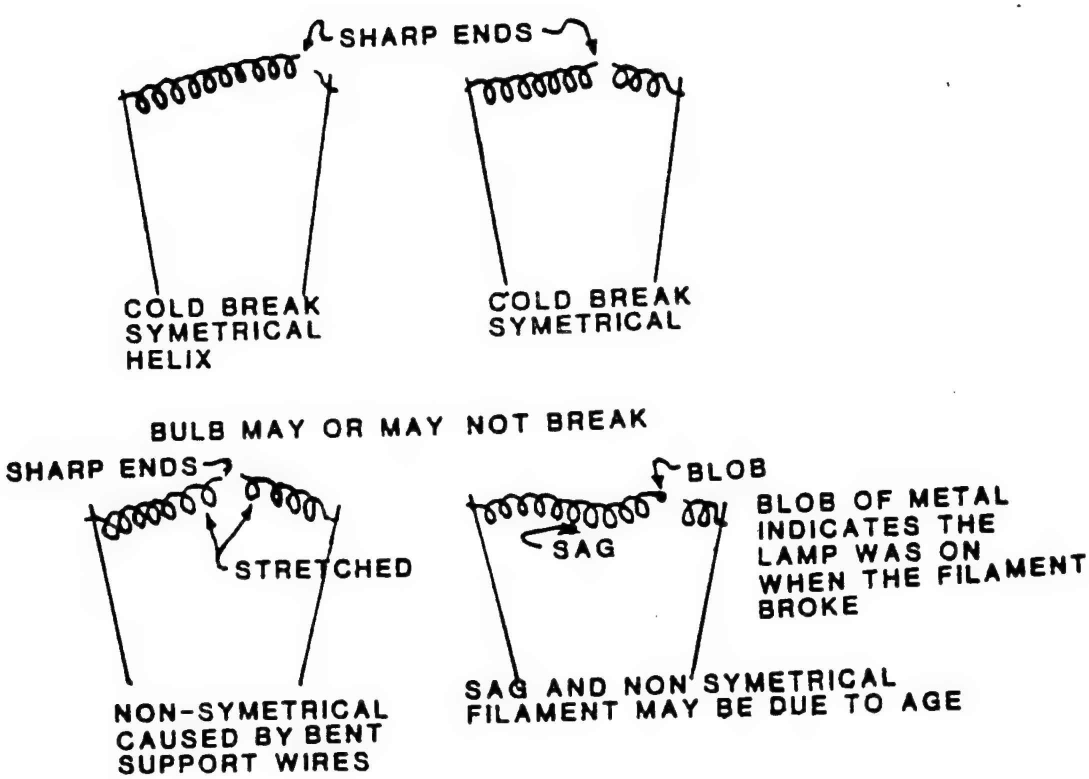


Figure 10-1 (page 8)

From Boating Accident Investigation, 1993

C. **Other Indicators**

1. When a lamp is burning and breaks, tiny beads of glass may melt and stick to the hot filament. (This is not too likely with low wattage lamps.)

2. If the glass breaks (or cracks) but the filament does not break, it will confirm that the light was not burning. If power were to be applied, the filament will burn out. If the glass is blackened and the filament has turned color, it probably indicates that the glass envelope is broken although the glass may also darken with age.

3. The direction of the filament stretch may indicate impact direction, but a sag may be due to age and vertical pounding. Filament supports may likewise bend on impact and may stretch the filament.

III. CHROMATICITY

The chromaticity, or color of a navigation light, is not likely to be a major factor in an accident unless the color is obviously wrong and might be misinterpreted. A faded green light may from a distance look like a stern light (white). To determine if the color is correct, the chromaticity testing must be done in a laboratory.

Opinion - this infers that it is wrong but normal. If it is wrong let the investigations find that the light is bad and move in a direction that requires that all nav. lites be tested. The same applies to the inverted lens.

IV. INTENSITY

The intensity requirements vary, depending on the function of the light. For example, on boats under 12 meters in length, the white masthead, stern and all-round lights are required to have a two-mile visibility, but the colored combination red/green light has a one-mile requirement. In the 12 to 20 meter class, all lights are required to be visible for two miles, except the masthead light, which is required to be a three-mile light. Table 14.1 shows the intensity requirements. Table 14.2 shows the range requirements for typical recreational boats.

TABLE 14.1

CANDELA INTENSITY FOR REQUIRED VISIBILITY

Required Range of Visibility in Nautical Miles (km)	Minimum Intensity in Candelas
1(1.9)	0.9
2(3.7)	4.3
3(5.6)	12.0
4(7.4)	27.0
5(9.3)	52.0
6(11.1)	92.0

Figure 10-1 (page 9)

From Boating Accident Investigation, 1993

V. VOLTAGE

In checking the navigation lights, remember that the light intensity is greatly affected by the system voltage and the investigator should, if possible, immediately check the voltage on both vessels. The critical and most important voltage reading is the voltage at the lamp of any navigation light when the lamp is energized. A voltage reading without the lamp in place will be higher because there is no load to cause voltage drop, the voltage drop at a navigation light should not exceed 3 percent. If the boat were operating, the voltage would probably be increased by the DC generator output; but if the boat were not operating, the voltage could be from the battery alone. If the output were dependent on the battery, then a determination must be made of how long the battery was operating from the time of the last charge and what on the vessel (bilge pumps, water pump, cabin lights etc.) used that battery for power.

It should be noted that the foregoing information, or at least confirmation of the information, will probably be obtained from witness interviews and care must be exercised in the approach to the individual being interviewed. Without mentioning navigation light intensity, simply ask for background information leading up to the accident. What was operating; when was the engine shut down; was there a dc generator running, etc.? With this information, it should be possible to determine the approximate battery voltage at the time of the accident.

VI. BARGE LIGHTS

Barges present a special case because the navigation lights frequently operate off their own small rechargeable battery, and the lights are only required to meet the intensity requirements in the horizontal plane. Another exception is that the intensity of non-electric lights need only comply with the intensity minimums "so far as is practicable."

The specific requirements for each vessel should be checked against the rules applicable to that vessel, the requirements for each vessel may not be the same. An unfortunate, and not accident is one involving a small boat which comes under the small boat requirements of the ABYC A16 Standard and a ship or barge. In one such incident, the battery-operated barge lights did not comply with the chromaticity, the intensity or cutoff angle requirements because the lights were modified to use a small flashlight bulb (because the larger required bulb wore out the battery too quickly) and the bulb was supported only by the internal wiring. Because of the method of support, the lamps were well off center and the light output was not even close to the requirements.

In lieu of laboratory testing for intensity, an acceptable investigative approach is to conduct a visibility test, on a clear dark night, over open water, over a marked distance, using an observer with 20/20 uncorrected vision. Document the weather conditions, visibility, date and time, locations, method of verifying distance, observers information (including recent optician statement) and other pertinent information. Operate the lights at the voltage determined from your investigation and position the lights at the angle that would have been encountered by the other vessel.

VII. CUTOFF ANGLES

The required cutoff angles again can only be accurately determined by laboratory photometric testing, but an estimate of whether a problem exists can be made on the boat by simply turning the lights on and observing the visual cutoff points. This should always be done from a distance to avoid parallax error. With the lights on, it is easy to see if the lamp is properly

Figure 10-1 (page 10)

From Boating Accident Investigation, 1993

centered and to judge if the wrong lamp has been used. The navigation light manufacturer should specify the proper lamp and that is the only lamp that should be used. A different lamp can totally change both the intensity and the cutoff angles and may effect the chromaticity.

If the navigation light lamp socket assembly is not properly secured, the socket may move within the housing and change the orientation of the filament. If the lamp does not have a vertical filament, rotation of the lamp will automatically change the cutoff angles because the filament will move horizontally. Some bayonet lamp bases have offset pins and will only go in one way, but other types with the pins on the same level can be in one of two positions. If the lamp has an Edison Base (see Figure 14.2), the filament position will change, depending how tightly the lamp is screwed in place and on physical tolerances that affect the number of turns before the base contact touches the socket contact.

For most standard bulbs, there is no attempt to critically locate or orientate the filament. This is also true of some lamps specifically manufactured for use in navigation lights. The alignment problem of the filament makes it critically important for the investigator to conduct the cutoff angle tests before the lamp is removed from the socket. For control of filament location, a vertical filament bulb is best, providing that filament support wire within the lamp is positioned in back of the filament. The filament support can cause a blank spot in the output curve, but the interruption is generally not significant.

Figure 10-1 (page 11)

From Boating Accident Investigation, 1993

TABLE 14.2

RANGE, COLOR AND VISIBILITY OF TYPICAL RECREATIONAL BOAT NAVIGATION LIGHTS

1. Side Lights

   Range - 1 mile for vessels less than 12 meters
   2 miles for vessels over 12 to less than 50 meters
   Colors - Red for port (left)
   Green for starboard
   Visibility - 112.5 degrees from right ahead--unbroken
   5 degrees above and 5 degrees below horizontal

2. All Around White Light or Anchor Light

   Range - 2 miles for vessels less than 50 meters
   Color - White
   Visibility - 360 degrees--unbroken
   5 degrees above and 5 degrees below horizontal

3. Masthead Light

   Range - 2 miles less than 12 meters
   3 miles less than 20 meters
   5 miles less than 50 meters
   Color - White
   Visibility - 112.5 degrees from straight ahead on each side--unbroken
   5 degrees above and 5 degrees below horizontal

4. Stern Light

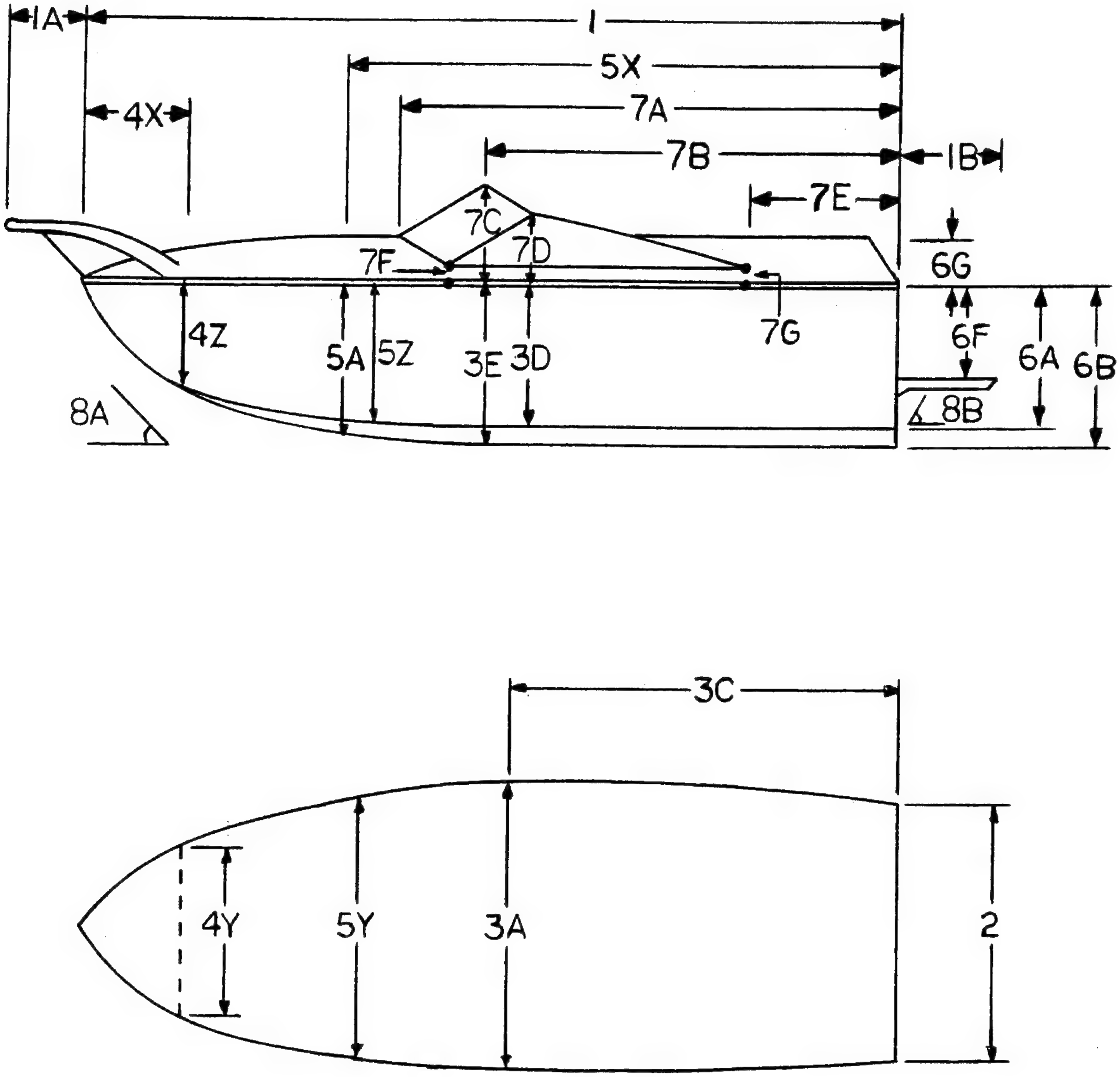
   Range - 2 miles for vessels less than 50 meters
   Color - White
   Visibility - 67.5 degrees from right aft on each side--unbroken
   5 degrees above and 5 degrees below horizontal

NOTES:

1. Vessels less than 7 meters that do not exceed 7 knots require only the light in Item 2 above.
2. Vessels less than 12 meters require Lights 1 and 2 above.
3. Vessels less than 7 meters, when at anchor, not in or near a narrow channel, fairway, anchorage, or where other vessels normally operate, are not required to exhibit an anchor light.

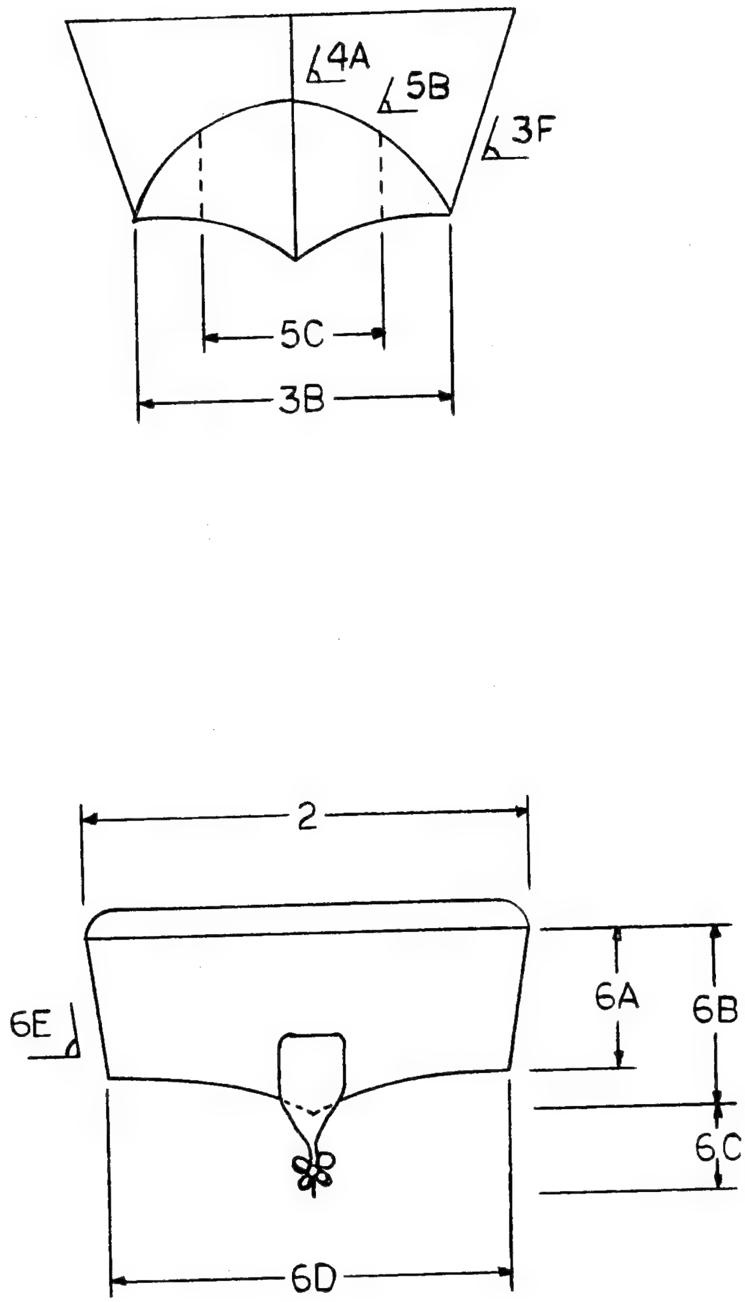
Figure 10-1 (page 12)

From Boating Accident Investigation, 1993



Suggested Measurements for Documenting a Boat's Shape.

Figure 10-2(a)



Suggested Measurements for Documenting a Boat's Shape.

Figure 10-2(b)

CHAPTER 11

ESTIMATING SPEEDS USING TRAJECTORY EQUATIONS

11.0 Introduction

One common question that investigators like to answer in a boat collision is, "How fast was that boat going?" This remains one of the most difficult questions to answer, yet some progress has been made in the development of tools that can provide this information. While developing material for UL's Boating Accident Investigation Seminars, simple methods for estimating speed for certain accident types were developed. These methods were based on conservation of energy methods and the trajectory motion equations. The purpose of this chapter is to briefly review those concepts and provide a summary of key formulas that were developed under that program.

Often it is not necessary to determine the precise speed that a boat was traveling just prior to impact. It may be sufficient simply to show that a boat was traveling at least a certain minimum speed. This speed may be well below the actual speed, but it may be sufficient depending upon the particulars of the situation. For example, it would probably be sufficient for the investigator to prove mathematically that a boat was traveling at least 25 mph prior to impact in a no wake zone, even if the boat's actual speed was 40 mph. This is assuming that the objective is to show that the boat was definitely traveling faster than "no wake" speed. The concepts reviewed in this chapter are generally conservative and are methods which are designed to estimate a minimum speed.

11.1 Conservation of Energy

Concepts of kinetic energy (KE) and potential energy (PE) were discussed in detail in Chapter 7. These concepts are important for they represent the fundamental principles on which the methods in this chapter are based.

One form of energy can often be converted into another. When a stunt car drives over a ramp, some of the KE is converted to PE as the car gains altitude. At the maximum height of the car's flight path, the maximum amount of PE has been obtained. As the car begins to fall back toward the ground, that PE is converted back into KE again. And so it is with many boat collisions. Typically, the boat is traveling at a certain speed, hits an object, flies through the air, and then returns to the water. It may, of course, land on another boat, the shore, a pier, or a host of other places. If some part of the boat's flight path can be documented, a minimum speed required to achieve that trajectory can be calculated. In accidents involving a trajectory, which means that the boat flies through the air for some height and distance,

we can often use conservation of energy methods to calculate the speed of the boat just before impact.

11.2 Speed Estimates Based on Height

A certain known amount of kinetic energy is required to propel an object to a particular height. This relationship is well established and discussed in detail in any good physics text. In order to arrive at this relationship, we will look at an example where all the kinetic energy which an object has is used to propel it vertically upward. At the maximum height which the object attains, all its velocity is zero, hence its KE is zero. Thus, all of its energy at that point is in the form of PE. We can calculate the maximum height of an object with mass of m, a velocity of V, as follows:

$$KE = PE$$

(11-1) $$1/2\ mV^2 = mgh$$

Solving for V, we arrive at:

(11-2) $$V = \sqrt{2gh}$$

where g is the acceleration due to gravity, 32.2 ft/sec^2

For example, if a boat strikes a seawall and lands such that the CG is 12 feet higher than it was prior to impact, the minimum speed of the boat was:

$$V_{min} = \sqrt{2(32.2)(12)}$$

$$V_{min} = 27.7\ ft/sec$$

Since we are calculating a minimum speed estimate, the answers are rounded down, not up. Note that the formulas are expressed in ft/sec not mph. To convert ft/sec to mph, use the following:

(11-3) Speed in mph = speed in ft/sec / 1.467 (approximately)

Thus, equation 11-2 provides the minimum velocity required to attain a certain height. It is important to realize what height is being discussed. We are concerned only with the change in height of the center of gravity (CG). The horizontal location of the CG can be located by balancing the boat, or by weighing the boat with scales at each end, and then calculating the CG location from each of the scales reading. A good approximation for the CG location can be made by balancing the boat on the trailer as well. Therefore, it is only the change in location of the CG that is to be used in the formulas that follow. Figure 11-1 and 11-2 show that it may not be as easy as one might think to document the CG location. In Figure 11-1 the change in height and distance of the CG is approximately the same as for any other portion of the boat since it landed in approximately the same attitude as that in which it was launched. Figure 11-2 illustrates an example of when extra care must be taken to determine the distance and height that the CG changed. In this example, one can not simply measure the change in height and distance of the bow or stern and use those values for the change in CG location. Instead, a careful diagram must be made that notes where the bow and stern are located, BEFORE the boat is moved! Obviously photos and complete documentation should be prepared of the boat in its "at rest" position. Then, the boat can be taken down and the CG location determined by an appropriate method. This data, and the diagram showing the location of the boat at rest, can be used to calculate the change in height of the CG from its initial position. The biggest sources of error in this method will be in properly determining the CG location at the beginning of the trajectory motion, and the CG location at the second point of interest. The second point of interest may be the maximum height, the maximum distance, or the point at which trajectory motion ceased. None of these points will generally be where the boat is located when the investigator finds it. A boat which has experienced an event such as that in Figure 11-2 will most probably not be resting in the position shown. It is important to remember that when using any of the trajectory formulas, two CG locations are desired:

(1) The CG location when the boat first begins its free flight trajectory motion. This is sometimes called the launch point.

(2) The CG location at the point of interest which is required for the formula being used. In most cases, this will not be the CG location where the boat is found after the collision. It is generally a difficult point to determine.

Equation 11-2 is useful because it requires very little information to develop a speed estimate. Unfortunately, it assumes that all of the kinetic energy is used to raise the object to the measured height. This is, of course, not true in any conceivable practical example. Energy is lost in a variety of ways in any real world collision that result in a change in height of the CG. Energy will be lost in forms of friction and air resistance in all practical cases. In most collisions, only a portion of the KE will be converted into PE. In a typical CWAV, much of the KE remains in the form of KE throughout the collision. In other words, the speed

of the bullet boat may change relatively little. You must also remember that the boat probably attained a height higher than that which you can normally document, thus further lowering the speed estimate. If the boat lands on a pier in such a way that the CG is now 12 feet higher than it was before the collision, it most likely achieved an even greater height during its trajectory.

11.3 Trajectory Motion

Equation 11-2 is a useful equation when estimating speeds for certain accident types. It allows the calculation of a minimum speed based only on the change in height of the CG during the accident. The other benefit of this equation is that one can be certain that the speed estimated is an absolute minimum regardless of the losses due to friction, the exact shape of the trajectory and many other factors. Unfortunately the answer provided may be too conservative to be of practical value.

Few boats hit an object and go straight up into the air. If the boat strikes an object and goes airborne, it will also travel some horizontal distance. This can be potentially useful information. Using trajectory equations, we can estimate the minimum speed, even if the only item we know is how far the boat traveled through the air.

Trajectory motion equations treat objects as a single point. They do not take into account air resistance and they assume that the motion is in one plane only. They also assume that the particle is experiencing a constant vertical acceleration downward due to earth's gravity. The horizontal component of acceleration is assumed to be zero. In reality, air resistance may alter these values somewhat, but in boat trajectories resulting from collisions, the effects are generally very small. For many practical problems, the trajectory motion equations will still provide good approximations. One nice convenience regarding trajectory motion is that the equations do not depend on the boat's mass. In other words, we do not need to know the weight of the boat to use trajectory motion equations. The general trajectory motion equation is:

$$(11\text{-}4) \quad y = x\,(\tan\theta_o) - \frac{gx^2}{2V_o^2\cos^2\theta_o}$$

where x and y are the horizontal and vertical coordinates of the particle. Vo = the initial velocity, and θ_o is the initial launch angle.

We will use what we know about the trajectory motion of the boat to estimate its minimum speed just prior to going airborne. We will also see that the more information we have, the better an estimate we can provide.

11.4 Estimating Speeds Based on Distance

Figure 11-3 shows the path that a particle travels if it is launched at various angles from 10 to 60 degrees at 20 mph. Clearly the greatest horizontal distance traveled is when the launch angle is 45 degrees. This is true anytime the object lands at the same elevation from which it was launched. If we are estimating the speed of a boat which was launched from the water and then returned to the water, then we can assume that the launch angle was 45 degrees in our calculations of minimum speed. This is the conservative approach, for if the angle was any greater or less than 45 degrees, the minimum speed required to traverse the measured horizontal distance will be greater than that calculated. This information is useful since it allows us to calculate a minimum theoretical speed for a boat if we know the horizontal distance that it flew through the air. If we start with the general equation for trajectory motion (equation 11-4), we can derive the equation which will provide this estimate. We will use equation 11-4 and solve the equation for V when y = 0 and $\theta_0 = 45$ degrees. The result gives us equation 11-5. The derivation is shown at the end of the chapter.

$$(11\text{-}5) \qquad V = \sqrt{Rg}$$

where R = Range

Look again at Figure 11-3. The maximum horizontal distance that the boat could possibly travel occurs when the launch angle is at 45 degrees. We call this maximum distance the range (R).

11.5 Speed Estimates Based on Height and Distance

So far we have discussed how to estimate the minimum speed of a boat if we can determine either how far or how high the CG of the boat traveled during its trajectory. Remember that equation 11-5 only applies to trajectories where the take-off point and landing point of the CG are at the same elevation. This is generally the case for CWAV accidents where one boat hits a second one, goes airborne, and lands in the water.

As a general rule, we can provide a better estimate of speed if we have more information that we can use in our formulas. If the boat lands at a point that is not at the same elevation from which it was launched, we must then record both the height and distance of the CG from the launch point. This information can be used to calculate the minimum speed necessary to launch the boat so that it lands in that location. The following equation will provide the minimum speed required for the CG of the boat to reach a certain height and elevation:

$$(11\text{-}6) \qquad V_{min} = \sqrt{g(h+\sqrt{d^2 + h^2})}$$

where d = the horizontal distance traveled by the CG
h = the change in height of the CG

The previous formula works even if the landing height is lower than the take-off height. Such might be the case if a boat jumped over a dam and landed in the stream below. If the elevation being used in the formula is lower than the original position, then a minus h must be used. If the elevation used in the formula is above the original CG position, then a positive value for h is used.

The above formula assumes that the most efficient angle was used to get to that point. If needed, the angle can be calculated from the following equation:

$$(11\text{-}7) \qquad \theta_{min} = 45+\frac{1}{2}(\tan^{-1} \frac{h}{d})$$

Take a look at Figure 11-4. This figure shows a flight path for a boat which was launched through the air and landed at a point about eight feet above the water on a level pier. The most efficient angle required to reach this point is approximately one-half the line of sight angle plus 45 degrees. Equation 11-7 calculates this angle.

Derivations for these equations may be found at the end of this chapter.

Equation 11-6 provides the most efficient angle for an object to reach a single point, described as height h above the original CG position, and horizontal distance d from the original CG position.

11.6 Clearing a Barrier

On rare occasions, a boat may strike an object and be launched high into the air before returning to the water. This situation can occur in a CWAV when the geometry, shape, and structure of the two boats combine to launch the bullet boat high into the air. Other situations may also occur which create the need to be able to estimate a better speed due to unusually steep trajectory.

Figure 11-5a shows the relationship for the distance and height of a 45 degree angle trajectory where the boat lands at the same height from which it took off. The maximum height occurs when x = R/2. At this point, the height is R/4. Thus, equation 11-5 will still provide the best estimate of speed when the height is equal to or less than R/4. If however, the height cleared is greater than R/4, then a better estimate of minimum speed can be computed, such as that provided by equation 11-8.

Figure 11-5b shows the trajectory of a projectile which clears a high barrier. Here, the height is greater than R/4. The launch angle must then be greater than 45 degrees. The minimum speed for this situation can be calculated from the following formula:

$$V_{\min} = \sqrt{g(2h + \frac{R^2}{8h})} \qquad (11\text{-}8)$$

Note that if this formula is applied in a situation where h = R/4, it will yield the same answer as equation 11-5. When using this formula, it is not necessary to know the range. The formula assumes that the barrier is at the midpoint of the horizontal range, which yields a conservative answer. In reality, there are very few real world collisions where this formula will be needed. In most cases, one of the other equations will be applicable.

11.7 Summary

This chapter briefly presented four basic formulas that can be used in trajectory analysis for collisions. The applicability of the formulas is not as limited as one might think. The formulas may work for objects thrown from a boat, in analyzing over-ride accidents, and a variety of other conditions. The largest source of error will generally be in determining the change in position of the CG of the boat.

11.8 Derivations

The derivations of equations 11-6 and 11-8 are presented in the following section.

DERIVATION OF EQUATION 11-6: (For situations shown in Figure 11-1)

$$V_{min} = \sqrt{g(h + \sqrt{d^2 + h^2})} \qquad (11\text{-}6)$$

Where: g = standard acceleration of gravitational pull, 32.2 ft/sec^2.

h = vertical distance of the end point above (+) or below (-) the trajectory starting point.

NOTE: This is not the highest point of the trajectory.

d = horizontal distance from starting point to the end point of the trajectory.

This formula gives the minimum velocity required for a projectile (boat, person or object) to travel to an end point which is a vertical distance h above (+) or below (-) the starting point and a horizontal distance d from its starting point:

Step 1: Basic Trajectory Equation is:

$$y = x \tan \theta - \frac{gx^2}{2V^2 \cos^2 \theta}$$

where:
- θ = Initial angle of trajectory
- V = Initial velocity
- g = 32.2 ft/sec^2
- x = Horizontal displacement relative to starting point at any subsequent time
- y = Vertical displacement at the distance x

Let $V_x = V \cos \theta$ be the horizontal component of the <u>initial</u> velocity, and $V_y = v \sin \theta$, the vertical component. If we neglect air resistance a projectile experiences no acceleration in the horizontal direction, and simple gravitational acceleration (-g) in the vertical direction. Hence, the position of the projectile as a function of time t is given by:

$$x = V_x t$$

$$y = V_y t - \frac{1}{2} g t^2$$

<u>NOTE</u>: $y = \frac{1}{2} gt^2$ is the equation for free fall and causes a negative acceleration as the projectile rises and a positive acceleration after passing the top of the parabolic arc. Therefore:

$$y = V (\sin \theta) t - \frac{1}{2} g t^2$$

$$= V (\sin \theta) \frac{x}{V \cos \theta} - \frac{1}{2} g \left(\frac{x}{V \cos \theta}\right)^2$$

$$= x \tan \theta - \frac{g x^2}{2 V^2 \cos^2 \theta}$$

<u>Step 2</u>: Obtain the optimal angle, namely the angle θ for which

$$\tan 2\theta = \frac{x}{y}$$

This is the angle corresponding to the lowest velocity (the most conservative estimate of the true velocity) required for a projectile to reach a point at range x and elevation y relative to the starting point. To obtain this formula, start by solving the basic trajectory equation for V, which gives:

$$V = \sqrt{\frac{g x^2}{2 \cos^2 \theta \, (x \tan \theta - y)}}$$

Now, the optimal angle for a given x,y is that for which

$$\frac{\partial V}{\partial \theta} = 0$$

This yields the following equation:

$$x \cos 2\theta + y \sin 2\theta = 0$$

NOTE: The partial derivative contains other factors as well, but this is the equation for the physical root of the problem being considered.

When rearranged;

$$\tan 2\theta = \frac{\sin 2\theta}{\cos 2\theta} = -\frac{x}{y}$$

Step 3: Obtain a formula for the minimum velocity involving only x and θ, namely

$$V_{min} = \sqrt{g\,x \tan\theta}\,, \quad \textit{as follows:}$$

$$= \sqrt{\frac{gx}{2\cos^2\theta\left(\tan\theta - \frac{y}{x}\right)}} \qquad \underline{\textit{From Step 2}}$$

$$= \sqrt{\frac{gx}{2\cos^2\theta\ (\tan\theta + \frac{1}{\tan}\ 2\theta)}}$$

$$= \sqrt{\frac{gx}{2\cos^2\theta\left(\tan\theta + \frac{1-\tan^2\theta}{2\tan\theta}\right)}}$$

$$= \sqrt{\frac{gx\tan\theta}{\cos^2\theta\ (2\tan^2\theta + 1 - \tan^2\theta)}}$$

$$= \sqrt{\frac{gx\tan\theta}{\cos^2\theta\sec^2\theta}}$$

$$V_{min} = \sqrt{gx\tan\theta}$$

Step 4: Express tan θ as a function of x and y to obtain

$$\tan 2\theta = \frac{2\tan\theta}{1 - \tan^2\theta} = -\frac{x}{y}$$

Rearranging:

$$x\tan^2\theta - 2y\tan\theta - x = 0$$

Solving the quadratic,

$$\tan\theta = \frac{2y \pm\sqrt{4x^2 + 4y^2}}{2x}$$

Substituting this into the last equation of Step 3,

$$V_{\min} = \sqrt{gx\left(\frac{y \pm\sqrt{x^2 + y^2}}{x}\right)}$$

NOTE: Only the positive combination gives a physically meaningful root

$$V_{\min} = \sqrt{g\,(y + \sqrt{x^2 + y^2}}$$

Substituting d and h for x and y:

$$V_{\min} = \sqrt{g\,(h + \sqrt{d^2 + h^2}}$$

DERIVATION OF EQUATION 11-8: (Refer to Figure 11-5)

The formula gives the minimum velocity needed to clear a barrier of height h at a horizontal distance ½R, which is half of the total horizontal distance (range) R from the starting point.

First, note that if there is no barrier present the minimum velocity would be that corresponding to a 45º trajectory. This trajectory automatically clears a height of h = ¼R, so for any barrier height less than ¼ of the range the minimum velocity will be the same as that for the 45º trajectory. Accordingly:

$$V_{\min} = \sqrt{gR} \quad if\ h \leq 1/4\ R$$

If h is > ¼ R the basic trajectory equation is:

$$y = x \tan\theta - \frac{gx^2}{2\,V^2 \cos^2\theta}$$

Where: θ is the initial angle
V is the initial velocity
h is the height at ½ R
R is the range
Note that the slope at d = R/2 is 0

In order to obtain the most conservative estimate of the initial velocity, it is assumed that the barrier is located at the mid-point (where d = ½ R).

If it is known that the barrier was cleared at some other point along the trajectory, then it would be better to use a two point formula which establishes the actual parobolic curve. A two point formula will give a higher velocity.

Using the basic trajectory equation and the equation for the derivative (slope),

$$y = x \tan\theta - \frac{gx^2}{2V^2 \cos^2\theta}$$

$$\frac{dy}{dx} = \tan\theta - \frac{gx}{V^2 \cos^2\theta}$$

The conditions become:

$$h = \frac{R}{2} \tan\theta - g\left(\frac{R}{2}\right)^2 / 2V^2 \cos^2\theta$$

$$0 = \tan\theta - \frac{g\left(\frac{R}{2}\right)}{V^2 \cos^2\theta}$$

The basic trajectory equation can be derived from the x and y equations of motion:

$$x = V_x t = (V\cos\theta)\, t$$

$$y = V_y t + 1/2\, a_y t^2 = (V\sin\theta)\, t - 1/2\, gt^2$$

(1) Plugging the second equation into the first gives:

$$h = \frac{R}{2}\tan\theta - \frac{\left(\frac{R}{2}\right) g \left(\frac{R}{2}\right)}{2 \quad V^2 \cos^2\theta}$$

$$= \frac{R}{2}\tan\theta - \frac{R}{4}\tan\theta$$

$$= \frac{R}{4}\tan\theta \quad \textit{or} \quad \tan\theta = \frac{4h}{R}$$

(2) Rearranging the second equation gives:

$$V = \sqrt{\frac{gR}{2\cos^2\theta\tan\theta}}$$

$$= \sqrt{\frac{gR}{2\cos^2\theta\dfrac{\sin\theta}{\cos\theta}}}$$

$$= \sqrt{\frac{gR}{2\cos\theta\sin\theta}}$$

$$= \sqrt{\frac{gR}{\sin 2\theta}}$$

Using trigonometric identity:

$$\sin 2\theta = \frac{2\tan\theta}{1+\tan^2\theta}$$

and combining (1) and (2) gives:

$$V = \sqrt{\frac{gR}{\sin 2\theta}}$$

$$= \sqrt{gR\left(\frac{1+\tan^2\theta}{2\tan\theta}\right)}$$

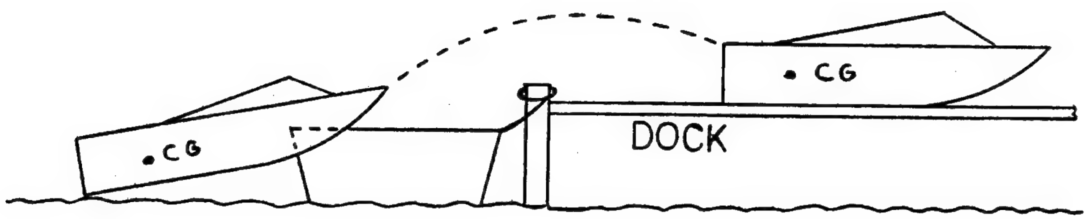
$$= \sqrt{gR\left(\frac{1+\dfrac{16h^2}{R^2}}{2\dfrac{R^2}{8h}}\right.}$$

$$= \sqrt{g\left(2h+\frac{R^2}{8h}\right)}$$

If there is positive physical evidence that the projectile followed an angle < 45° the

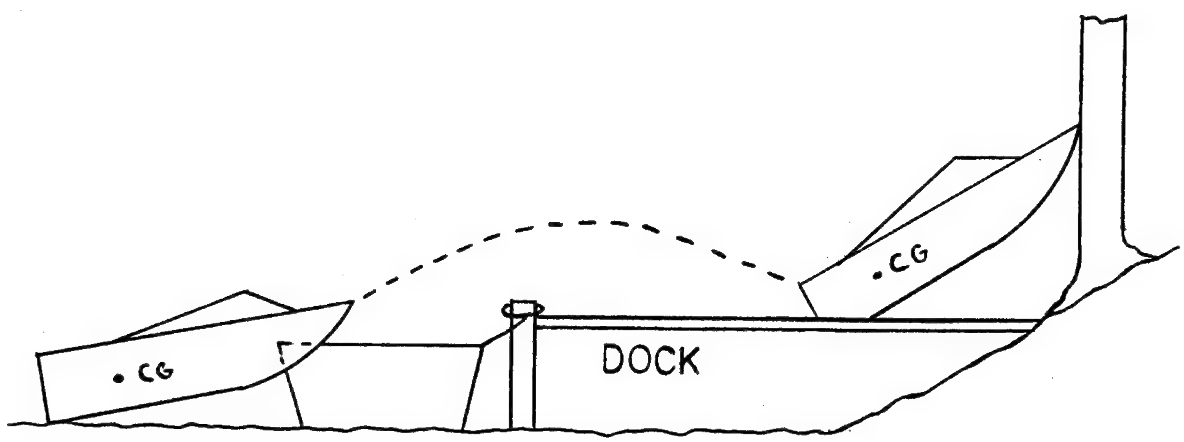
$$V = \sqrt{g\left(2h + \frac{R^2}{8h}\right)}$$

formula can be used. Care must be used because the formula uses the midpoint.



The Change in CG Height is About the Same as the Change in Height of Any Other Part of the Boat in this Accident.

Figure 11-1



The Change in CG Height is More Difficult to Determine When the Boat Lands in this Orientation.

Figure 11-2

Trajectories at 20 mph

Initial slopes: 10°
20°
30°
40°
45° (darker)
50°
60°

Points at $\frac{1}{10}$ second intervals.

Trajectory equations:

$$y = x \tan\theta_o - \frac{gx^2}{2v_o^2 \cos^2\theta_o} \qquad \text{where} \qquad \begin{cases} y & = \text{vertical distance} \\ x & = \text{horizontal distance} \\ g & = 32\ \frac{\text{ft}}{\text{sec}^2} \\ v_o & = \text{initial velocity in } \frac{\text{ft}}{\text{sec}} \\ \theta_o & = \text{initial angle} \end{cases}$$

$$\text{maximum height} = \frac{v_o^2 \sin^2\theta_o}{2g}$$

$$\text{range} = \frac{v_o^2 \sin 2\theta_o}{g}$$

$$\text{time of flight} = \frac{2v_o \sin\theta_o}{g}$$

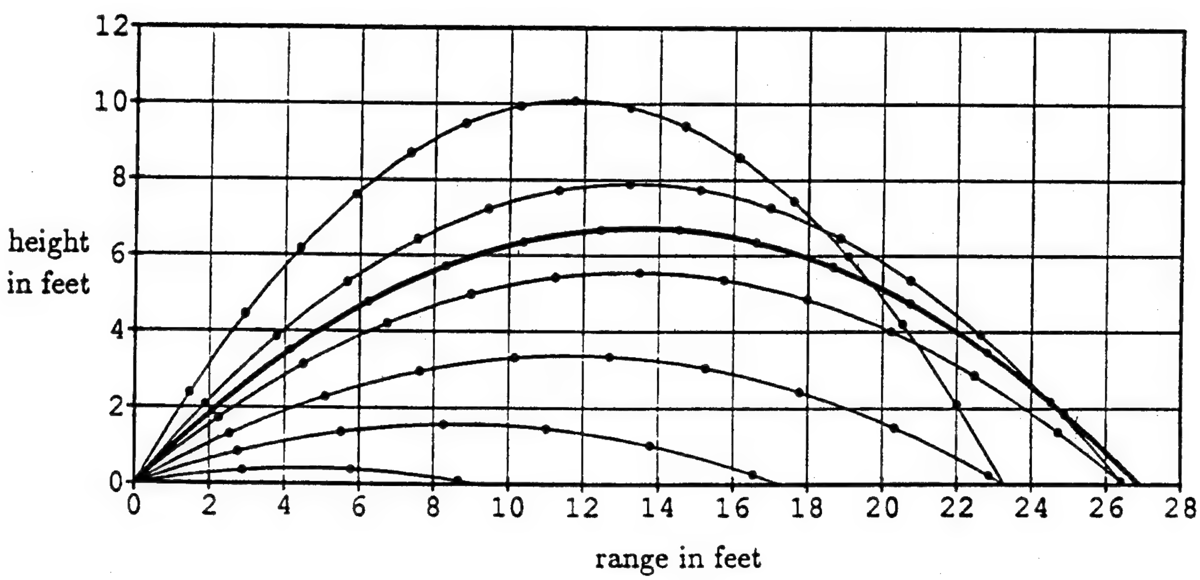


Figure 11-3

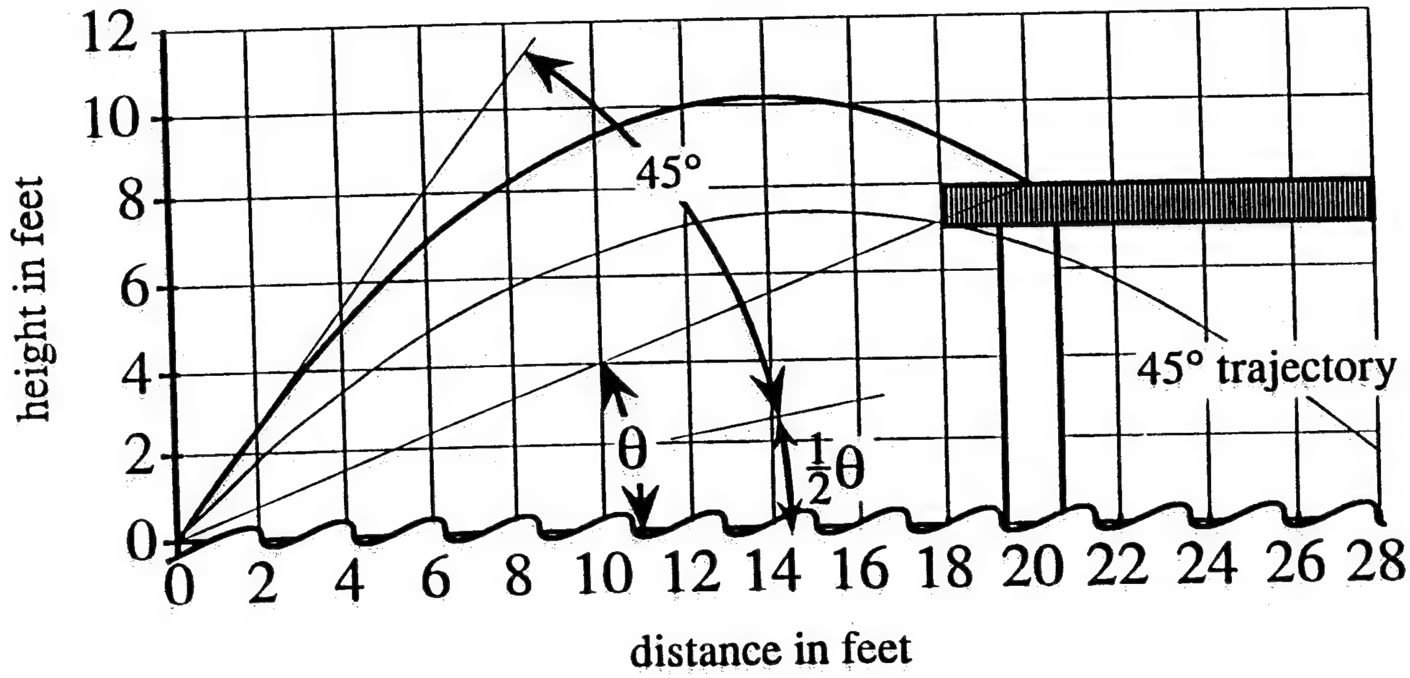
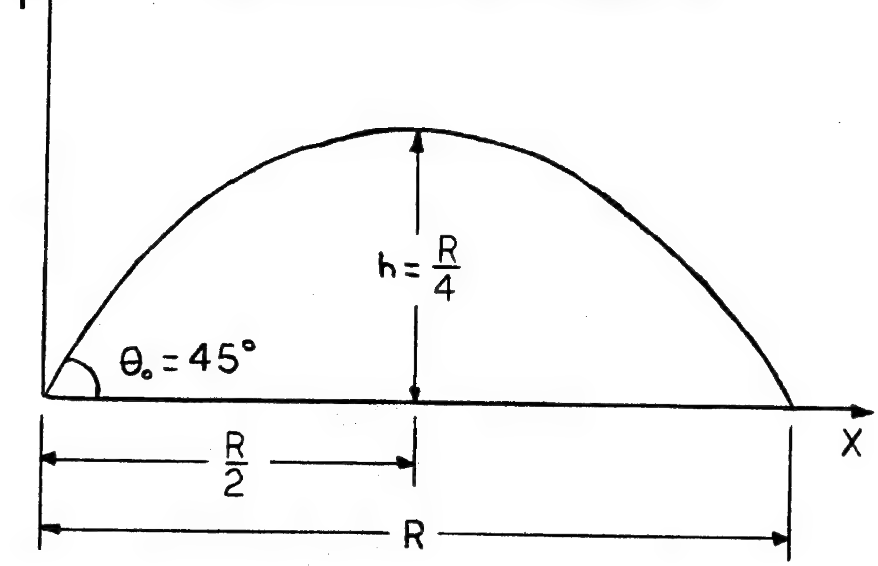

12
10
8
6
4
2
0
height in feet
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
distance in feet
45°
θ
$\frac{1}{2}\theta$
45° trajectory

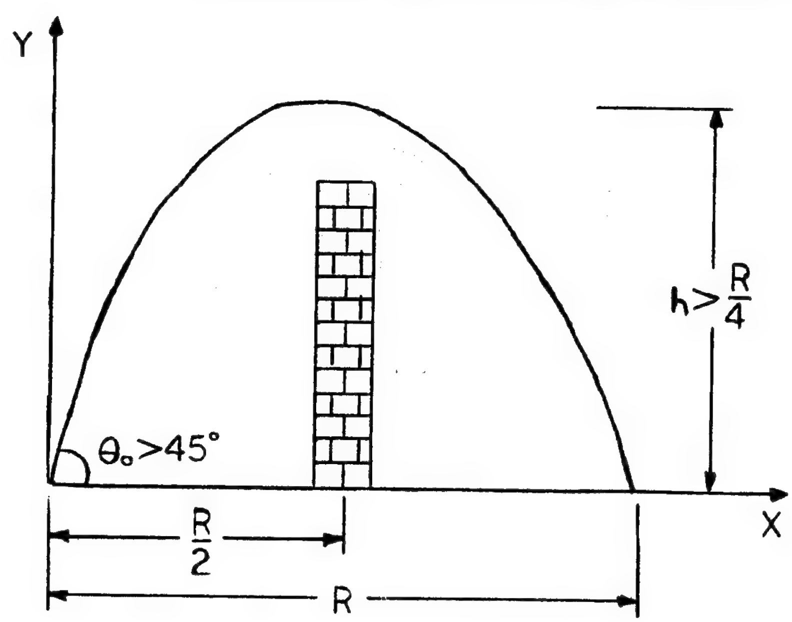
Figure 11-4

Trajectory When Launch Angle is 45°



(A)

Trajectory When Launch Angle is Greater Than 45°



(B)

Figure 11-5

CHAPTER 12

ADVANCED THEORIES OF BOAT COLLISION ACCIDENT RECONSTRUCTION

12.0 Introduction

Chapter 11 provided some tools that can be used to estimate minimum speeds in boat accidents that involve a trajectory. Realistically, the trajectory equations may be useful in as few as 20% of the collision accidents. Are there any methods available which can be used to estimate speeds for two boat collisions based on physical evidence alone? These are the most difficult types of accidents to analyze because of the variety of variables. Classic methods of automobile accident reconstruction often fail us completely in two boat collisions. Therefore, new and different techniques must be used to analyze these accidents.

In this chapter, we offer a few concepts that may serve as the basis for the reconstruction of these difficult types of accidents. Neither these theories nor their practical applicability have been fully explored. The reader is urged to use caution in attempting to apply these concepts to accidents today, as more research into each area is necessary before the validity of each method can be fully known. The methods presented here nonetheless provide a possible basis for the growth and advancement of the field. Early theories in many fields are later improved upon, some are later proven wrong, and others remain the cornerstone of a field for years to come. Only time will determine the significance of the concepts presented here.

This chapter will discuss three possible methods for analysis of accidents for the purposes of estimating speeds, impact angles or both. First we will discuss techniques of striation analysis from which impact angles and speeds may be estimated. Next, we will look at the role of friction and how it can possibly be taken into account in certain accident types. Lastly, we will discuss methods to determine the Minimum Threshold Velocity (MTV). The MTV is defined as the minimum speed required for one boat to clear a second vessel.

12.1 Estimated Speeds Compared to Minimum Speeds

It is important to realize that the methods in this chapter differ significantly from the trajectory equation methods discussed in Chapter 11. The trajectory equations are well known and well established. They have been applied in various forms to automobile accident reconstruction for years to accident types called flips, vaults, and airborne accidents. Those methods, when properly

applied, can yield minimum speeds at which an automobile travelled. The answers are designed to be conservative, and will be, if the equations are applied properly.

The methods provided in this chapter are means of estimating speeds. The answers are not necessarily conservative, they are merely estimates. It is important when attempting to apply these principles that the investigator understand the difference between estimating speeds and calculating minimum theoretical speeds.

12.2 Striation Mark Analysis

Striation marks are evidence that two surfaces came into contact. These marks tell us much more than one might think. They can indicate the relative severity of the contact forces by the depth of the scratches. They may leave clues as to which parts of the objects were in contact due to the material transferred. Perhaps most important to us in this context, they indicate the relative direction in which each object was traveling.

Striation marks, in one form or another, are common in all boat collisions. They are most useful in the analysis of over-ride collision accidents. The striations on the bottom of the bullet boat provide valuable information about the relative speed of each boat during impact. Careful analysis of the striation marks can help the investigator estimate impact angles and relative speeds of both boats.

12.2.1 The Basics of Striation Mark Analysis

The striation analysis techniques primarily apply to over-ride accidents where the bullet boat literally crosses over the top of the target boat. It is one of the few techniques available to obtain data on the speeds based solely on physical evidence when both boats were moving at impact.

Let's look at the striation marks which are created during some simple collisions. Figure 12-1 is a diagram which shows a collision between two boats. The bullet boat, which is the boat that travels over the top of the other vessel, is traveling at 25 mph ($V1 = 25$), while the target boat is stationary ($V2 = 0$). The bullet boat strikes the target boat at a 90 degree angle, and we will assume the impact point is in line with the CR (Center of Rotation) such that the target boat does not pivot during the impact. As a result of this impact, the bullet boat will have striations on the bottom of the hull parallel to its centerline. The struck boat will have striation marks on the top surface that run at 90 degrees to the centerline of the boat.

Figure 12-2a shows the same two boats, except now the target boat is traveling at the same speed as the bullet boat. We will assume that the impact again occurs at 90 degrees. Figure 12-2b shows the striations on each boat after impact. The bullet boat now has striations which run at a 45 degree angle on the bottom of the hull. The target boat now has striations which run across the deck at 45 degrees also. The striations were made while the two boats were in contact with each other.

Figure 12-3 shows a top view of the collision which occurred in Figure 12-2 in progress. The bullet boat is shown in contact with the target boat as the former travels over the top of the latter. At this moment during the collision, the target boat is cutting a set of striation marks in the bottom of the hull of the bullet boat. The marks begin at A and travel toward B. These marks are represented by the solid line. Also at this moment, any appendages on the bottom of the hull of the bullet boat are making a set of striation marks on the deck of the target boat. These marks are represented by the dashed line, and begin at A and travel toward B. These marks are important because each set of striation marks represents the velocity of one boat relative to the other. Texts on basic dynamic analysis and relative motion can be consulted if you need more in depth explanations of the previous statement.

The striation marks in Figure 12-3 provide important information without any further analysis. These marks establish the relative orientation of the two boats during at least part of the collision. After a collision, it may be important to determine the relative orientation of each vessel during the impact. If the striation marks represented by Figure 12-2 can be located on each boat, the orientation can be established simply by placing the two boats such that the marks are parallel with each other. Caution is advised however since there are two positions which will meet this criteria, the correct one and a second one that is 180 degrees off! Sufficient evidence is usually available to help the investigator choose between the two orientations. In the example in Figure 12-2, one side of the boat should clearly be identifiable as the struck side, thus making it easy to choose the correct orientation during the collision.

12.2.2 Striations and Velocities as Vectors

Clearly some relationship exists between the impact angles, the velocities of the two boats, and the resulting striation marks. If we could determine that relationship, it would give us a possible tool to estimate some of these parameters. Expressing these quantities as vectors will provide us with a method for analysis.

As a quick review, a vector is a quantity that has both a magnitude and a direction. Clearly, velocities are vectors since they possess both qualities. But what about striation marks? Striation marks clearly have a direction, but what about a magnitude? To answer that question, look at Figure 12-4.

Figure 12-4 shows us in a graphical form the relationships between velocity vectors and the striation marks. The velocity of the bullet boat, V1, is drawn on the positive x axis. The velocity of the target boat, V2, is drawn on the positive y axis.

These directions are consistent with the example in Figures 12-2 through 12-4. We have drawn in the line S, which represents the direction of the striation marks on the bottom of the bullet boat hull. By observation of the striation marks in our example in Figure 12-2, we knew that the striation marks were at a 45 degree angle on both boats. If we assumed that S was a vector, what would it represent? If we let S represent the striation marks found on the bottom of the bullet boat hull, then the vector S would represent the velocity of the target boat relative to the bullet boat. The result is that the vector S as drawn in Figure 12-4 is equal to the vector difference of the two velocity vectors as expressed in equation 12-1 below:

$$\overline{S} = \overline{V2} - \overline{V1} \qquad (12\text{-}1)$$

The striation marks which remain on the bottom of the hull of the bullet boat following an over-ride accident are an indication of the relative velocities of the two boats, and can be represented by S. Technically, the striations are not vectors. The relative velocity of the two boats is a vector though, which given certain assumptions, will be parallel to the striation marks (see section 12.2.9.) The striation marks then are not really vectors, but are indications of the relative velocities of the two boats, which is a vector. We will let the symbol S represent the relative velocity difference, and in subsequent sections refer to this as the vector S, or the striation vector.

The previous paragraphs provide an argument for the meaning of the vector S based primarily on observations. The next section provides a mathematical method for arriving at the same conclusion.

12.2.3 Mathematical Derivation of the Striation Vector

The key to solving the riddle of the significance of the striation marks can be found by studying Figure 12-3. The marks on the bottom of boat 1, the bullet boat, have a special significance. These marks indicate the velocity of the target boat relative to the bullet boat. The basic concepts of relative motion can now be applied to show the mathematical relationship of the velocities of the two boats, to the striation marks. These concepts are covered in most any book on engineering dynamics or basic physics. These concepts are best illustrated by an example.

Figure 12-5 shows both boats traveling at a speed of 25 mph, headed toward each other at right angles. This is the same scenario presented originally in Figure 12-2. We will assume once again the boat 1 is the bullet boat, and that it will pass over the top of boat 2. We can now predict the angle of the striation marks if we can calculate the velocity of boat 2 as seen from boat 1, realizing that this is different than what the apparent velocity of boat 2 would be to an observer standing on shore.

We clearly know what the velocities of each boat are as seen from a fixed reference frame, such as an observer on shore. But how do we determine the apparent or relative velocity of one boat in relation to the other? The set of axes XYZ represents the fixed reference frame. We would like to know the velocity of boat 2 as seen from boat 1. Thus, we will place a set of axes xyz, on boat 1. The axes represented by xyz are moving relative to the XYZ in translation only, no rotation is occurring. The origin of xyz is attached to boat 1. The reason for this exercise in setting up various axes now becomes clear. From concepts of basic relative motion, the following relationship exists:

$$V_{XYZ} = V_{xyz} + \dot{R} \qquad (12\text{-}2)$$

The terms are explained as follows:

V_{XYZ} is the velocity of an object relative to the fixed reference, XYZ.

V_{xyz} is the velocity of an object relative of an object relative to the moving reference frame, xyz.

$\dot{R}$ (pronounced R dot) is the velocity of the moving reference frame relative to the fixed reference frame.

Equation 12-2 can be expressed in words as "The velocity of an object relative to a fixed reference frame XYZ is equal to the velocity of the object relative to the moving reference frame xyz, plus the velocity of the origin of xyz relative to the fixed reference XYZ."

In this example, the velocity of boat 2 relative to XYZ is equal to +25j, with j representing the unit vector in the y direction. The velocity of boat 1 is equal to R dot and is +25i,

with i representing the unit vector in the x direction. We can now solve for the velocity of boat 2 relative to xyz (which is boat 1).

$$(12\text{-}3) \qquad Vb2_{XYZ} = Vb2_{xyz} + \dot{R}$$
$$+25j = Vb2_{XYZ} + 25i$$

$$(12\text{-}4) \qquad Vb2_{XYZ} = -25i + 25j$$

Equation 12-4 is the velocity of boat two as seen from boat 1 for our example. This velocity is drawn as a vector in Figure 12-6, and we can see that the resultant vector is at a 45 degree angle to the centerline of both boats. This vector is of course the same vector as the striation vector, shown in Equation 12-1. In order to clarify this, we will repeat both equations with the matching terms in the same place in each equation:

$$(12\text{-}5) \qquad Vb2_{XYZ} = Vb2_{XYZ} - \dot{R}$$

$$(12\text{-}6) \qquad \overline{S} \quad = \quad \overline{V2} \quad - \quad \overline{V1}$$

Equation 12-6 is the notation we will use when we need to derive a striation vector.

It must be remembered that S is a vector which represents the striation marks found on the bottom of the bullet boat following an over-ride accident and is the velocity of the target boat as seen from the bullet boat.

12.2.4 Practical Applications

How can we use the information developed to estimate speeds in a collision? So far we have shown how to calculate the striation angle if the speed of both boats is known. In most collisions, the speed of neither boat is really known, but the angle of the striation marks on the bottom of the bullet boat can be measured.

The procedure can be reversed and the striation angles can be used to help estimate the speeds of the boats involved. First, we need one more piece of information in order to be able to estimate boat speeds, and that is the impact angle.

Estimating impact angles can be done with a reasonable degree of accuracy in certain accident situations. We will cover in some detail how to do this later in the chapter. For now, in order to illustrate how speeds can be estimated using striation marks, we will assume that the impact angle can be determined with a reasonable degree of accuracy.

Armed with an estimate of the impact angle and the angles of the striation marks on the bottom of the bullet boat, we now have the tools to calculate what is known as the Velocity Ratio (VR). The VR is defined as:

$$VR = \overline{V2} \,/\, \overline{V1}$$

This is simply the ratio of the speed of the target boat to that of the bullet boat. A VR of two tells us that the target boat was traveling at twice the speed of the bullet boat.

The equation for calculating the VR is provided below:

$$(12\text{-}7) \qquad VR = \sqrt{(a2)^2 + [\,(a2)\ (\tan \theta 2)]^2}$$

where a2 is defined as:

$$(12\text{-}8) \qquad a2 = \frac{\tan \theta 3}{\tan \theta 3 - \tan \theta 2}$$

The angles used in the equations above are explained below and shown in the diagram in Figure 12-6.

$\theta 2$ = the angle of the velocity vector $\overline{V2}$

$\theta 3$ = the angle of the striation vector $\overline{S}$

The angles are always measured from the positive x axis.

Note that the VR is not defined when $\theta 2 = \theta 3$. The VR is also not defined when $\theta 2$ or $\theta 3$ are equal to zero or 360 degrees.

Equation 12-7 is referred to henceforth as the VR equation. The VR ratio alone will not tell us the speed of either boat, but can in itself be useful data. If the speed of one boat is known, the speed of the second boat can then be estimated if the VR is known. Even without knowing the speed of either boat, the VR may provide sufficient information to help prove or disprove a certain scenario. If the bullet boat, boat 1 is clearly on plane, and the VR ratio is equal to 0.5, then the target boat must have been traveling at a speed of at least half of the bullet boat. If the minimum planing speed for boat 1 is 18 mph, then boat 2 was traveling at least nine mph. Therefore, if the operator of boat 2 claims he was sitting still when struck, the investigator has a tool to show otherwise.

Figure 12-7 shows certain characteristics of the VR equation that should always be kept in mind. For any given value of $\theta 3$, the striation angle, there will always be a variety of values of $\theta 2$, the impact angle of boat 2, which could result in the observed

striation angles. Figure 12-8 shows that values of $\theta 2$ do have limits. When $\theta 3$ is between zero and 180 degrees, the value of $\theta 2$ is always greater than zero, but less than $\theta 3$. This may be expressed as:

$$0 < \theta 2 < \theta 3 \quad ; \text{ for } \theta 3 \text{ between 0 and 180 degrees.}$$

When $\theta 3$ is between 180 and 360 degrees:

$$\theta 3 < \theta 2 < 360 \; ; \text{ for } \theta 3 \text{ between 180 and 360 degrees.}$$

The last expression says that when the striation angle $\theta 3$ is between 180 and 360 degrees, the velocity vector V2 is always less than 360 degrees, but greater than $\theta 3$.

12.2.5 Application of the VR Equation

The VR equation can be used to help estimate the VR based on the striation angles and the estimated impact angle. The obvious problem with this application is that a considerable error may be made when estimating impact angles. Striation angles can be measured, but they too offer more of a challenge to measure accurately than one might expect. Still, the most subjective number in the equation is the impact angle. To evaluate the usefulness of the VR equation, we must know how precise the data provided must be to produce worthwhile results.

Since the impact angle is the most subjective number in the equation, we will first look at the sensitivity of the VR equation to this parameter. The sensitivity of the VR equation to the impact angle $\theta 2$ depends upon the value of $\theta 2$. One easy method for determining the sensitivity of the VR equation to errors in $\theta 2$ is to plot a range of values of $\theta 2$ while holding $\theta 3$ constant.

As an example, let's assume that $\theta 3$ is equal to 25 degrees. According to Figure 12-8, valid values of $\theta 2$ are between zero and 25 degrees. Figure 12-9 shows us a graph and tabulation of the VR for values of $\theta 2$ ranging from 0 to 24 degrees.

We see several interesting characteristics based on this graph. First, there exist a minimum VR regardless of the value of $\theta 2$. Second, the value of the VR approaches infinity as $\theta 2$ approaches $\theta 3$ for this graph. From examining the graph, it is clear that the VR ratio is very sensitive to errors in the striation angle measurement as the impact angle ($\theta 2$) approaches the striation angle ($\theta 3$).

12.2.6 The Nature of the VR Curve

The graph in Figure 12-9 is only a small portion of a much larger picture. If we remove the limits on $\theta 2$ defined in Figure 12-8, we can see the larger graph of which Figure 12-9 is only a small portion. Figure 12-10 shows a graph of the VR with $\theta 2$

ranging from 0 to 360 degrees for a striation angle of 30 degrees. This graph alone shows several important characteristics summarized below:

- The value of the VR is undefined when $\theta 2 = \theta 3$, and when $\theta 2 = \theta 3 + 180$ degrees

- The value of the VR approaches infinity as $\theta 2$ approaches $\theta 3$

- There is clearly some minimum value of the VR, and a corresponding angle of $\theta 2$

- The graph incorrectly suggests that there are values of $\theta 2$ which can produce a defined VR for the given striation angle which are outside the limits of those given in Figure 12-8.

It is not especially obvious, but we would get exactly the same plot if we set $\theta 3$ = to 210 degrees (30 + 180). Thus, we have a graph which mathematically calculates all the values of the VR for values of $\theta 2$ from zero to 360 degrees. We must remember that the only part of the graph that is valid are the values of $\theta 2$ which are between zero and 30 degrees, represented by the shaded area A in Figure 12-10. These limits are consistent with those defined in Figure 12-8. If $\theta 3$ was equal to 210 degrees, the values of the VR for $\theta 2$ between 210 and 360 degrees would then be the only valid portion of the graph, represented by shaded area B. While the values in the middle of the graph for $\theta 2$ between 30 and 210 degrees provide a mathematical solution, they do not offer a realistic vector solution to the velocity diagram, and are thus not valid in the estimation of the VR.

It is important to note the kind of trouble one can get into if the correct part of the graph is not used. For region A in Figure 12-10, where $\theta 3$ = 30 degrees, the minimum theoretical VR is approximately one. For the region represented by B however for $\theta 3$ = 210 degrees, the minimum VR is equal to 0.5. Selecting invalid values of $\theta 2$ which are outside the limits of those defined in Figure 12-8 can lead to incorrect conclusions about the minimum VR. The shaded area C, for values of 02 greater than 30 and less than 210 degrees, the solutions are not physically achievable.

12.2.7 Sensitivity of the VR Equation for Various Striation Angles

Figure 12-9 shows us a very typical VR curve. The curve clearly has a flat portion at the bottom where it is not especially sensitive to changes in the impact angle, and steep slopes which are very sensitive to changes in the impact angle. We will see that the shape of the curve changes significantly depending upon the value of the striation angle for which it is plotted.

Figure 12-11, 12-12 and Figure 12-13 are VR curves for $\theta 3 = 5$, 45, and 85 degrees respectively. Since the VR curve for $\theta 3$ and $\theta 3 + 180$ degrees are identical, the curves in Figures 12-11 through 12-13 are also the curves for $\theta = 185$, 225, and 265 degrees respectively. Compare these curves to the one in Figure 12-10. We can see that the curve in Figure 12-11 is much less sensitive to changes in $\theta 2$ over a larger range than the curve in Figure 12-12. Studying figures 12-10 through 12-13 leads us to the conclusion that as $\theta 3$ increases from 0 to 90 degrees, that the VR curve becomes more sensitive to changes in the impact angle. We can also see that the minimum value of the VR changes depending upon the value of $\theta 3$.

12.2.8 Minimum VR for Varying Values of the Striation Angle

The graphs in Figures 12-10 through 12-13 show us that regardless of the value of the impact angle, that for any given value of $\theta 3$, there exists some minimum value of the VR. This is useful, for without knowing anything about the impact angle, we can estimate the minimum VR based solely on the striation angle. In this section, we want to develop a method for calculating the minimum VR for any given value of $\theta 3$.

If the limits for $\theta 2$ as defined in Figure 12-8 are kept in mind, the minimum values of the VR and the corresponding values of $\theta 2$ can be defined as follows:

For $0 < \theta 3 <= 90$:

Min VR = 1.0

$0 < \theta 2 < \theta 3$

For $91 < \theta 3 < 270$:

Min VR is as shown in Figure 12-14.

VR is undefined for $\theta 3 = 180$ degrees.

$\theta 2 = \theta 3 - 90$ when $90 < \theta 3 < 180$
$\theta 2 = \theta 3 + 90$ when $180 < \theta 3 < 270$

For $271 < \theta 3 < 360$:

Min VR = 1.0

$270 < \theta 2 < 360$

VR is undefined for $\theta 3 = 360$ degrees.

The diagrams shown in Figure 12-14 help illustrate each of these limits. We will briefly discuss each of the diagrams to help explain why these limits exist. Figure 12-14a shows a striation angle drawn through the origin of 20 degrees as an example. The same vector is also shown originating from the end of the vector V1. The striation vector represents the vector difference of the two velocity vectors, and must form the third leg of the triangle created by V1 and V2. Clearly then, V2 can have angles of $\theta 2$ anywhere between zero and $\theta 3$. The shorter the vector V2, the lower the velocity ratio. As you can see, V2 gets shorter (representing a lower velocity) as $\theta 2$ approaches zero. The limit of the VR as $\theta 2$ approaches zero is one. In other words, there is no value for $\theta 2$ that will result in V2 having a magnitude less than one for values of $\theta 3$ between zero and 90 degrees.

Once $\theta 3$ exceeds 90 degrees, the VR can be less than one. By examining the graphs in Figures 12-10 through 12-13, we can see that the minimum VR appears to occur when $\theta 2$ is at a 90 degree angle to $\theta 3$. Figure 12-14b shows an example where $\theta 3 = 120$ degrees. The shortest value of V2, and therefore the minimum VR, occurs when V2 is at right angles to S. These principles apply as well in Figure 12-14c, where we see an example where $\theta 3 = 225$ degrees. We see now that the minimum VR occurs when $\theta 2 = \theta 3$ minus 90 degrees, for values of $\theta 3$ between 90 and 180 degrees. The minimum value of VR occurs at $\theta 2 = \theta 3 + 90$ degrees for values of $\theta 3$ between 180 and 270 degrees.

In Figure 12-14d, we address an example where $\theta 3$ is greater than 270 degrees. This example parallels that in Figure 12-14a. The minimum value of V2 can never be less than one, thus establishing the minimum VR as 1.0.

Figure 12-15 shows the minimum VR for a range of values of $\theta 3$ between 0 and 360 degrees. The tabulated values for values of $\theta 3$ between 90 and 270 degrees are shown in Figure 12-16a and 12-16b.

12.2.9 Potential Problems Applying The VR Equations

The VR equations can help to analyze an over-ride collision, but like all equations, they are based on certain assumptions. If the assumptions do not hold true, the accuracy of the analysis is questionable. The VR equations assume that both boats are traveling in a direction parallel with the longitudinal centerline of the boat. In other words, the equations assume that neither boat is skidding across the water laterally. Such slight skidding may be possible if either boat had taken evasive action right before impact.

Another potential problem with the VR equations is that they require a good set of striation marks with which to work. By a good set of marks, we are referring to a set of straight scratches which can be measured by referencing the striation angle to the centerline of the boat. Most power boats do not have flat bottoms, making it difficult to truly establish the angle of the striation

marks to the centerline of the boat. The situation is further complicated if one or both boats are engaged in a turn at the time of the accident. If the bullet boat enters a severe roll during contact with the other vessel, the striation marks which are made on the bottom of the hull are different than they would have been if the boat was level. The VR equations assume that the striation marks were made on a flat portion of the bottom of the bullet boat while the boat was level, or equivalent. The degree to which the roll angle affects the results of the analysis depends upon many factors, including the hull shape and the roll angle at the time of contact.

It must be remembered that in order to use the VR equations effectively, the striation marks on the bottom of the hull of the bullet boat are assumed to be velocity vectors which indicate the relative velocity of the target boat to the bullet boat at the time of impact. The reasons for this were discussed earlier in section 12.2.3. Anything in the collision that creates a condition where the striation marks are not representative of this velocity vector will adversely affect the accuracy of the striation analysis.

Perhaps a more obvious solution to the problem is to obtain a range of values for the VR which are useful in the particular situation involved. The application of this topic is so new that it is difficult to estimate the real accuracy with which striation marks can be measured. Any reasonable analysis will have to allow for some variance in the striation angle, though just how much is still open to discussion. It appears reasonable that the striation angles should be measurable to an accuracy of plus or minus five degrees on the hull surface. Based on this assumption, an analysis would need to allow for a ten degree variance of the value of $\theta 3$. There are certain portions of every VR curve where the VR becomes extremely sensitive to slight changes in the impact angle. As an example, in Figure 12-9, the VR changes from 2.4 to 4.8 while $\theta 2$ varies from 15 to 20 degrees.

Working with an accident on the sensitive part of the VR curves will require accurate input data or great inaccuracies in the calculated VR will result.

12.2.10 Unusual Striation Patterns

Two common types of striation patterns are worth mentioning because they can be very confusing when they are first observed. During some collisions, especially those where the boats may not have been traveling at very high speeds, the angles of the striation marks on the bottom of the bullet boat near the bow may vary from those toward the rear. Of course the striations, if any, on the deck of the target boat may vary in a corresponding manner.

These variations may occur for several reasons. If both boats stay pointed in the same direction during the impact, but the velocity of one or both decreases while they are still in contact, the relative velocity of the two boats changes. This change is reflected in the changing striation angles. The striations which

are closer toward the bow of the bullet boat on its hull bottom will give a good indication of the VR closer to the time of initial impact. This is one situation where the striation marks on the target boat near the impact point may be the best indication of the VR during the initial impact.

The striation marks could also change angles if one boat or the other had its bow deflected during the initial impact. A change in heading, even if the actual velocity remained constant would result in a change in the striation angles as the collision progressed.

Another phenomenon worthy of mention is striation marks which appear as sweeping arcs, perhaps with a radius of only a few feet. Such marks on the bottom of the bullet boat can be the result of a piece of material from the target boat breaking away during the collision. If these sweeping arcs can be found on the bullet boat and the target boat in a matching location, it is a possible indication that one boat pivoted on top of the other while the two were in contact. Accident number 6 in chapter 13 provides a good example of an accident where the bullet boat rotated on top of the target boat.

The key concept to remember about striation marks is that they indicate the relative motion of the two objects while they were in contact. For most new to the accident investigation field, this is a difficult concept to apply. The temptation is to view and analyze the motion of the bullet boat over the target boat as though the target boat were sitting still. Most people do this without even realizing it. Figure 12-3 and 12-5 are good diagrams to study which illustrate the concepts of relative velocity.

12.2.11 Velocity Ratio Equations Summary

Despite its potential problems in certain applications, the VR equations are a potentially valuable and powerful tool for use in the analysis of over-ride collisions. The purpose of the VR equations is to estimate a velocity ratio when the impact angle and striation angles are known. A possible but less likely application is to use the graph in Figure 12-15 to estimate a possible range of values for the impact angle if the VR were somehow known.

The VR ratio equations are important because they are some of the few tools available to help estimate boat speeds in a two boat collision. The equations are not used to calculate boat speeds directly, but are used to find the velocity ratio of the two boats involved. Specifically, the VR provides the speed of the target boat compared to that of the bullet boat. Remember that in the definition of the VR, the velocity of the bullet boat was defined as one. If any other data is available to help substantiate the speed of one boat, the speed of the other can then be estimated. Remember that these equations apply only to over-ride collisions, and that $\theta 3$ is the angle of the striations on the bottom of the bullet boat.

A set of equations could be developed based on striations that appear on the top surface or deck of the target boat. The same principles apply, but everything would be referenced back to the target boat instead of the bullet boat. Our experience during the field investigations showed that better striation marks are usually found on the bottom of the bullet boat rather than the top surface of the target boat. This is the reason the equations were presented based on striations measured on the bullet boat.

The use of the VR equations depends on a reasonable estimate of the impact angle. The estimate of the impact angle is not an easy judgement to make. This becomes the subject of section 12.3.

12.2.12 Graphical Methods For Estimating The VR

For those who do not particularly enjoy the use of equations, we will present in this section a method of determining the VR using graphical methods. Since it was shown earlier that the striation marks can be represented by velocity vectors, the VR ratio can be estimated by using simple vector algebra. The steps below summarize how to estimate the VR when the striation angles and impact angles are known.

1. Draw a set of xy axes with V1 on the positive x axis with a value of 1. Call the point on V1 at x=1 point A.

2. Draw the striation vector S at the angle $\theta 3$, with the beginning of this vector at point A.

3. Draw V2 with its beginning at the origin at the angle $\theta 2$. The origin is the intersection of the xy axes. V2 should intersect S. If it does not, you have made a mistake somewhere! Go back and double check the values you used for $\theta 2$ and $\theta 3$.

4. Measure the length of V2 between the origin and the intersection with S.

5. The VR is determined by the length of V2 divided by the length of V1 (which is one by definition).

Your drawing should look similar to the one in Figure 12-4 when you are finished.

12.2.13 Mathematical Derivation of the VR Equation Using the Vector Approach

This section contains the mathematical derivation of the VR equation. This approach is based on vector algebra.

Terms:

V1 = Velocity of boat 1, the bullet boat
V2 = Velocity of boat 2, the target boat
S = The striation vector

From the discussion in section 12.2.3, we know the following to be true:

$$(12\text{-}9) \qquad \overline{S} = \overline{V2} - \overline{V1}$$

For each vector, we will use the notation:

a = component in the x direction
b = component in the y direction

such that any vector V = a + b

We will now re-write each of the vectors as follows:

V1 = a1 + b1
V2 = a2 + b2
S = a3 + b3

Then:

$$(12\text{-}10) \quad V2 - V1 = (a2+b2) - (a1+b1) = (a3+b3)$$

From the above expression:

$$(12\text{-}11) \qquad a3 = a2 - a1$$

$$(12\text{-}12) \qquad b3 = b2 - b1$$

We will adopt the standard convention that the magnitude of V1 is always equal to one, and V1 is drawn on the positive x axis. We will calculate the magnitude and velocity of V2 to arrive at the velocity ratio (VR). The VR is defined as V2/V1, but since V1 = 1, it follows that VR = V2. The VR then is in relation to V1. As an example, if the VR = 2, then the speed of boat 2 was twice the speed of boat 1.

Because of the convention adopted for V1, V1 can be written as:

(12-13) $$V1 = 1 + 0$$

thus a1 = 1 and b1 = 0. Substitute these values into equations 12-11 and 12-12:

(12-14) $$a3 = a2 - a1$$

(12-15) $$b3 = b2 - 0$$

Now we can use the information on the striation angles and estimated angles of impact to develop an equation for the magnitude of V2.

We will add the following definitions:

$\theta 2$ = the impact angle measured from the positive x axis
$\theta 3$ = the striation angle, defined as the angle of the striations as found on the bottom of the hull of the bullet boat. This angle is also measured from the positive x axis.

From basic trigonometry, we know that:

$$\tan\theta 3 = \frac{b3}{a3} \quad and \quad \tan\theta 2 = \frac{b2}{a2}$$

therefore:

$$b3 = a3(\tan\theta 3) \quad \text{and} \quad b2 = a2(\tan\theta 2)$$

From equation 12-14 we know that:

a3 = 1 - a2, and from equation 12-15 we know b3 = b2; substituting into the previous equation and solving for a2 yields:

$$\begin{aligned} a3(\tan\theta 3) &= a2(\tan\theta 2) \\ (a2 - 1)\tan\theta 3 &= a2(\tan\theta 2) \\ \tan\theta 3 - a2(\tan\theta 3) &= a2(\tan\theta 2) \\ a2(\tan\theta 3) - \tan\theta 3 &= a2(\tan\theta 2) \\ a2(\tan\theta 3) - a2(\tan\theta 2) &= \tan\theta 3 \end{aligned}$$

$$a2 = \frac{\tan \theta 3}{\tan \theta 3 - \tan \theta 2} \qquad (12\text{-}16)$$

Since b2 = a2(tan θ2), we can now write b2 as:

$$b2 = \frac{(\tan \theta 3)\ (\tan \theta 2)}{\tan \theta 3 - \tan \theta 2} \qquad (12\text{-}17)$$

Remember that a2 and b2 are the x and y values of the Vector V2. Thus, in order to find the magnitude of V2, we can use the distance formula.

$$V2 = \sqrt{a2^2 + b2^2} \qquad (12\text{-}18)$$

If we leave a2 as it is defined in equation 12-16, we can write equation 12-18 as follows:

$$|V2| = \sqrt{a2^2 + [(a2)\ (\tan \theta 2)]^2} \qquad (12\text{-}19)$$

Equation provides us with the absolute value of the magnitude of V2. The VR is actually numerically equal to this value since we assumed that V1 = 1 in the beginning of the derivation.

12.2.14 Derivation of the VR Equation Using Trigonometry

Equation 12-19 is one approach to solving what can be viewed as a simple trigonometry problem. After all, what we really need is the magnitude of V2, which is the length of the line segment V2.

We can use the Law of Sines to solve for the magnitude of V2. The derivation for the Law of Sines can be found in most any geometry or analysis text. The Law of Sines basically states:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C} \qquad (12\text{-}20)$$

Figure 12-17 shows the how the sine law can be applied to the velocity diagram. We will first derive the relationship for values of θ3 between 0 and 180 degrees. The correlation between the diagrams in Figure 12-17a and 12-17b is as follows:

$a = S$, $b = V1$, $c = V2$
$A = \theta 2$, $C = 180 - \theta 3$

We really need to determine the length of V2, therefore we will apply the law of sines. First, we need to establish the values of B and C in terms of the impact angles and striation angles. First, find C:

$C = 180 - \theta 3$

Now find the value of B:

$$\begin{aligned} A + B + C &= 180 \\ \theta 2 + B + (180 - \theta 3) &= 180 \\ B &= 180 - \theta 2 - (180 - \theta 3) \\ B &= \theta 3 - \theta 2 \end{aligned}$$

Now substitute and use the law of sines:

$$\frac{c}{\sin C} = \frac{b}{\sin B} \qquad (12\text{-}21)$$

$$\frac{V2}{\sin(180 - \theta 3)} = \frac{1}{\sin(\theta 3 - \theta 2)} \qquad (12\text{-}22)$$

$$V2 = VR = \frac{\sin(180 - \theta 3)}{\sin(\theta 3 - \theta 2)} \qquad (12\text{-}23)$$

We have now established a fairly simple formula for the VR in terms of the sine of θ3 and θ2. The above derivation was specifically for values of θ3 between zero and 180 degrees.

We can derive the formula for V2 with values of $\theta 3$ between 180 and 360 degrees using Figure 12-18a and 12-18b as a basis. The only difference is the way that values for A and B are calculated. The values for A and B are as follows:

$$A = 360 - \theta 2$$

$$B = 180 - A - C$$
$$B = 180 - (360 - \theta 2) - (\theta 3 - 180)$$
$$B = 180 - 360 - \theta 2 - \theta 3 + 180$$
$$B = \theta 2 - \theta 3$$

For values of $\theta 3$ between 180 and 360 degrees. When these values are substituted into equation 12-21, the following results:

$$\frac{V2}{\sin(\theta 3 - 180)} = \frac{V1}{\sin(\theta 2 - \theta 3)} \qquad (12\text{-}24)$$

$$V2 = VR = \frac{\sin(\theta 3 - 180)}{\sin(\theta 2 - \theta 3)} \qquad (12\text{-}25)$$

Equation 12-25 provides the equation for the VR for values of $\theta 3$ between 180 and 360. The equation is nearly identical to equation 12-23 which provided the VR for $\theta 3$ between zero and 180 degrees. Equation 12-25 and 12-23 are, in fact, equivalent. We can prove this by considering the following equations:

From trigonometry,
$\sin(-x) = -\sin x$

Now let $x = 180 - \theta 3$, *then* $-x$ *is*
$-x = -(180 - \theta 3)$
$-x = -180 + \theta 3$
$-x = \theta 3 - 180$

since $\sin(-x) = -\sin x$, *substitute*:
$\sin(\theta 3 - 180) = -\sin(180 - \theta 3)$

If we perform this substitution on both the numerator and denominator on the equation found in 12-23, it will look like the equation as shown in equation 12-26, and we arrive at equation 12-27, which is identical to equation 12-25. Thus, we now see that the VR can be calculated for any value of $\theta 3$ using equation 12-27. The plots shown in Figures 12-9 through 12-13 and 12-15 can also be obtained by using equation 12-27. The plots are identical for all valid values of $\theta 2$. In some ways the plots generated using equation 12-27 are better than those shown in the figures, because

some of the invalid values are not shown. The shaded area labeled C, shown in Figure 12-10, would not be shown if equation 12-27 were used to generate the plot.

$$V2 = VR = \frac{\sin(180 - \theta 3)}{\sin(\theta 3 - \theta 2)} = \frac{-\sin(\theta 3 - 180)}{-\sin(\theta 2 - \theta 3)} \tag{12-26}$$

$$V2 = VR = \frac{\sin(\theta 3 - 180)}{\sin(\theta 2 - \theta 3)} \tag{12-27}$$

12.3 Estimating Impact Angles In Over-ride Collisions

The actual impact angle is important for several reasons. For one, the impact angle may help the investigator determine who was at fault, or what view of the navigation lights an operator had prior to the accident. The impact angle may also be important because it is one of the factors necessary to determine the velocity ratio.

The earlier chapter on documentation techniques covered the basic elements that need to be identified in order to estimate the impact angles. Having good documentation of all the relevant damage is the first step toward an accurate reconstruction.

Unfortunately, there is no magic formula or prescribed technique that will always provide an accurate estimate of the impact angle. We have however been able to develop a few techniques that can at least help to identify a range of possible impact angles in most over-ride collisions. The accuracy of the estimate depends largely upon how well the remaining physical damage can be analyzed.

Estimating impact angles requires good documentation of the relevant damage to both boats, and an understanding of the concepts of relative motion presented in the discussion of the VR equations. The basic steps required are summarized as follows:

1. Document all relevant damage to both boats.
2. Find all unique points which are candidates for damage matching.
3. Determine where possible the relative position of one boat to the other during as many points during the collision as possible.

4. Create a scale drawing of the top view of both boats including relevant damage areas and striation marks.

5. Trace the scale drawing of the bullet boat onto a transparency.

6. Be sure that all striation marks on the bottom of the bullet boat's hull and the target boat's top surface are shown in each diagram.

7. Line up the orientation of each boat so that the striation marks on both drawings are parallel to each other.

8. Note all damage points where damage matching was able to identify the location of one boat relative to the other during the impact.

9. Try to follow the path of the bullet boat over the top of the target boat by doing the following: Place the transparency of the bullet boat over the diagram of the target boat in one of the positions determined by step 8. Rotate the drawing of the bullet boat until the striations of the two boats are parallel. Move the drawing of the bullet boat over the target boat in the direction of the striation marks, not in a direction parallel to the centerline of the bullet boat. If the two happen to be the same, so be it, but the striation marks should not be parallel to the centerline of the bullet boat if the target boat was moving (uless the impact angle was zero or 180 degrees). Watch for orientations of the two boats where other damage points from step 8 line up.

10. We should now find an orientation of the bullet boat where the transparency of the bullet boat can be slid over the top of the drawing of the target boat in the direction of the striations which are consistent with points from step 8. For example, this technique should drag the lower unit exactly through the location which coincides with the torpedo hole on the side of the target boat. Remember to slide the boats only in the directions of the striations.

The above techniques can be used to help identify the initial impact point, even when the structure which was initially struck was missing after the collision. The key to showing that the impact angle is accurate is to be able to find at least two or three points where damage matching positively places the two boats in a given orientation at different times during the impact. A good set of striation marks can then be used to help estimate the initial impact point. These techniques were used on several of the field accidents covered in chapter 13.

In some accidents, the impact angle and precise initial impact point can not be determined. This is often because of inaccuracies in documenting the damage locations or small errors in the scale diagrams. Usually the scenario which makes the damage points line up is not completely consistent with the striation angles and vice versa. In these cases, it is best to estimate the impact angles as a range. It is usually possible to clearly establish the limits beyond which it could not have been, and it may also be possible to estimate an angle which is the most probable.

One word of caution is in order here. The temptation in many accident reconstructions is to formulate a scenario early in the investigation which takes into account most of the evidence, but not all. Often the first guess is influenced by witnesses or even by the particular cases on which the investigator previously worked. The scenario will fit most pieces, but there are still a few obscure marks or pieces of damage that simply can not be explained by the initial guess. This is a dangerous place to leave a reconstruction. In an accident reconstruction, every piece of evidence and damage tells a story that is consistent with what actually happened. Since we know so little about boat dynamics during two boat collisions, the real scenario may be something that no one has yet to envision as possible. The reconstructionist must continue to dig and analyze until all the pieces fit or until those that do not can be explained. Sometimes the pieces that do not fit are the results of an earlier accident or may have been damage caused during the salvage operation. These possibilities must not become scapegoats for the reconstructionist's inability to explain a certain piece of evidence.

12.4 The Minimum Threshold Velocity

One method that can help to estimate speeds in a two boat collision is to examine a concept called the Minimum Threshold Velocity (MTV). Once again, this technique is useful for over-ride collisions. Many accidents involve situations where the bullet boat clearly runs completely over the top of the target boat. It requires a certain amount of energy for the bullet boat to accomplish this task. The amount of energy required depends upon the path which the CG of the bullet boat took as it rode over the target boat.

In order to estimate the MTV, the path followed by the CG of the bullet boat must be estimated. Generally, we want to determine the path requiring the lowest amount of energy and calculate a minimum velocity from there. The path can be estimated based on the geometry of both boats and the location of the CG of the bullet boat. Figure 12-19 shows an example of an over-ride accident where such calculations may be useful. The bullet boat made contact with

the target at points A and B, but cleared the bow completely. Based on this information, we can reconstruct a minimum energy path that the CG of the boat could have travelled. We now have a trajectory motion problem that can be solved by methods discussed in chapter 11.

One factor makes this approach rather challenging. We do not have sufficient data on collision dynamics to be able to estimate the degree to which the target boat was depressed into the water, thus lowering the path of the CG. From viewing videotapes of experimental collisions, it appears that the effect of this factor in some collisions may be negligible, especially in scenarios where a small boat strikes a large boat. The effect of the target boat being depressed into the water is probably more than offset by the fact that once the minimum energy path is established, there is an extremely great chance that the actual path involved was one requiring much greater energy. This technique does not account for any sliding through the water that the target boat may have done during the impact. If the collision was from the stern, chances are that the struck boat moved forward some considerable distance during the collision. If the bullet boat still cleared the bow of the target boat in this scenario, then there is clearly some additional distance to be added to the trajectory for which this technique does not account.

It is helpful to determine the longitudinal position of the CG of the bullet boat. Fortunately, it is generally not necessary to determine the height of the CG in these situations. Since trajectory motion equations calculate a velocity based on a change in height in CG, and not the literal height of the CG during the trajectory, the precise vertical location is not required. When establishing the minimum energy trajectory, the vertical location of the CG may be assumed to be near the bottom of the hull for most 16 to 18 feet I/Os and inboards. Outboards will have a slightly higher CG. Remember that since we are interested only in changes in CG location during the trajectory, the precise CG coordinates in the vertical plane are not generally required.

The MTV concept assumes that the struck boat is stationary. If two boats are traveling toward each other, the speed of the target boat will contribute toward the bullet boat's ability to ride over the top of it. The concept may apply when the velocities of the two boats are perpendicular to each other, though this application has not yet been investigated.

12.5 Predicting Launch Angles

The MTV and trajectory concepts could be used to greater advantage if we knew the launch angles of the target boat. Early experimental collisions indicate that for certain scenarios, it may be possible to estimate the launch angle. Collisions involving a T-Bone impact where the target boat was stationary were fairly

repeatable. It is usually possible to estimate a minimum launch angle. This information can help to obtain a much more accurate speed estimate depending upon the damage done to the target boat.

Figure 12-20 shows a T-Bone impact with a stationary target boat. The outdrive of the I/O has cleared the far gunwale of the target boat. The typical hole where the gearcase penetrated the initial hull side is easily located. The gearcase hole, and the location of the gunwale on the far side can be used in conjunction with the geometry of the bullet boat to estimate the launch angle. This does not take into account the fact that the target boat may have been at a significant roll angle when the damage was done. Experience gained from conducting experimental collisions has shown that while the target boat may roll toward the bullet boat initially, by the time the outdrive of the bullet boat reaches the initial hull side of the target boat, the target boat may have returned to a level roll attitude.

Estimating the launch angles in this type of collision can be especially useful if other data on the trajectory is known, such as how far the boat flew through the air after contact. Even if this is not known, the CG locations at points A and B, on Figure 12-20 can be used to better estimate the minimum speed of the bullet boat.

The concepts of MTV and launch angle need further research before they can be fully developed. Nonetheless, they appear to be viable approaches to reach a few more answers when analyzing boat collisions.

12.6 What About Friction?

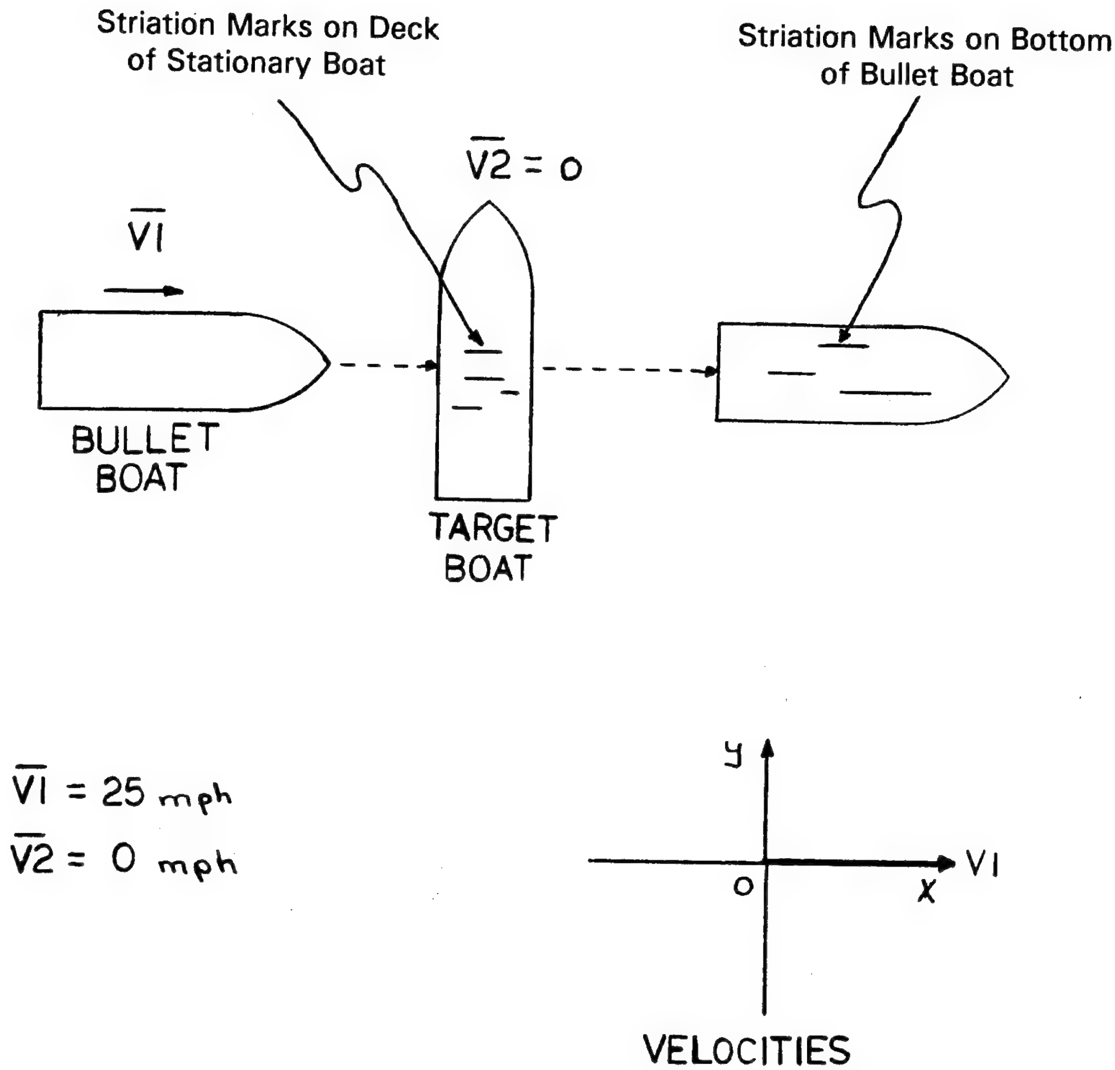
The kinetic energy lost by the bullet boat during an impact goes into many forms. For some collisions, the energy lost due to friction is significant. If we could somehow account for the energy lost due to friction in a collision, we could increase our minimum speed estimates, thus getting closer to the actual impact speed of the bullet boat.

Friction is especially likely to account for a significant portion of the energy lost during collisions which involve a long contact area. The best examples of this occur when a bullet boat runs over the target boat directly from the stern. Running over the boat lengthwise typically results in a longer contact area. In these cases, the target boat may begin to move forward during the impact, thus increasing the contact times.

Unfortunately no experimental testing has been done to date to attempt to actually measure the dynamic friction coefficients which exist in these circumstances. This is one area of consideration for future research. If friction coefficients are developed for these types of collisions, it will provide the reconstructionist with one more tool to assist in estimating minimum speeds prior to impact. Refer to accident number seven in Chapter 13 for additional information on friction analysis.

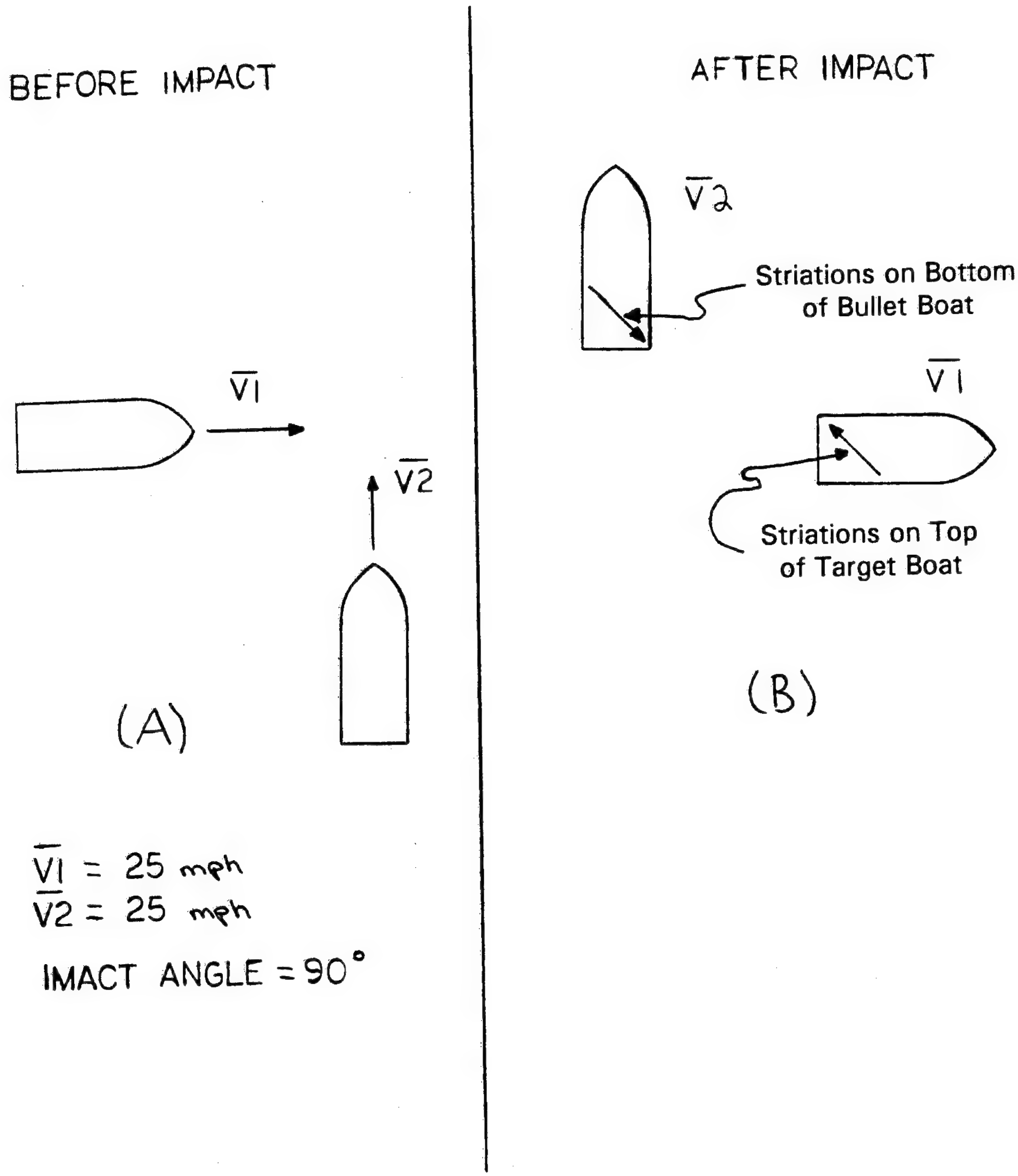
12.7 Conclusion

The techniques presented in this chapter attempt to break new ground with regard to reconstructing two boat collision accidents. Anyone who attempts to employ these techniques should have a thorough understanding of the concepts involved. Hopefully, time and future research will improve on those techniques presented here. With additional research and testing, more sophisticated techniques may be developed in the future that will allow an accurate reconstruction of an even wider variety of accident types. Recent developments in computer technology have brought the capability of dynamic simulation to the desktop PC. The implications of these advances have yet to be fully realized.The concepts presented in this chapter could be greatly enhanced with the assistance of today's simulation technology.



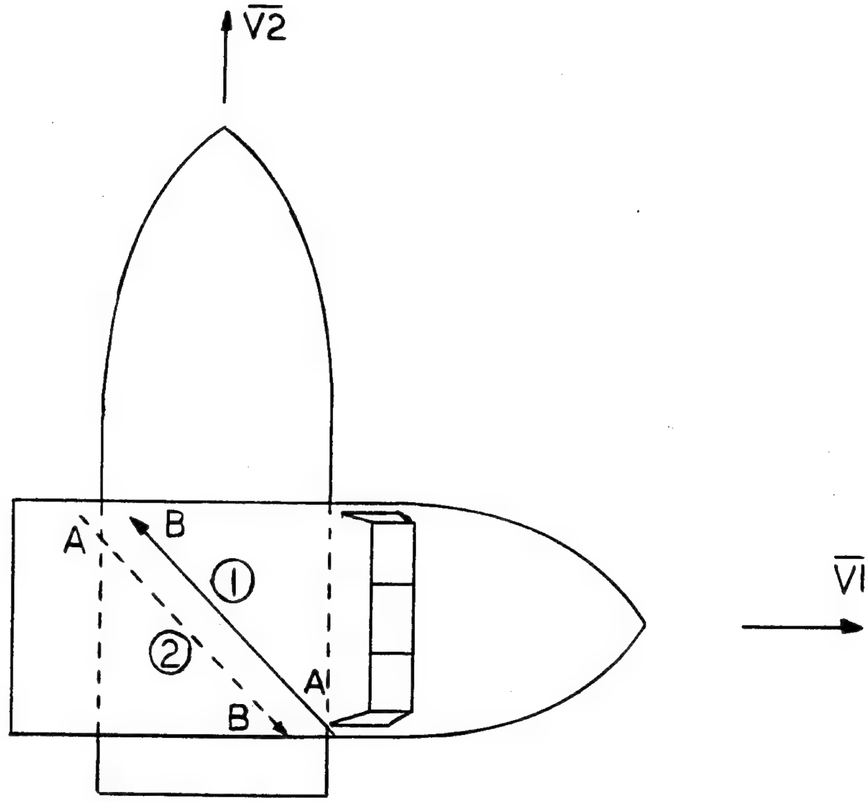
When the Target Boat is Stationary, Striation Marks on the Bottom of the Bullet Boat are Parallel to the Centerline.

Figure 12-1



When Both Boats are Moving, The Striation Marks are at an Angle to the Center Line.

Figure 12-2

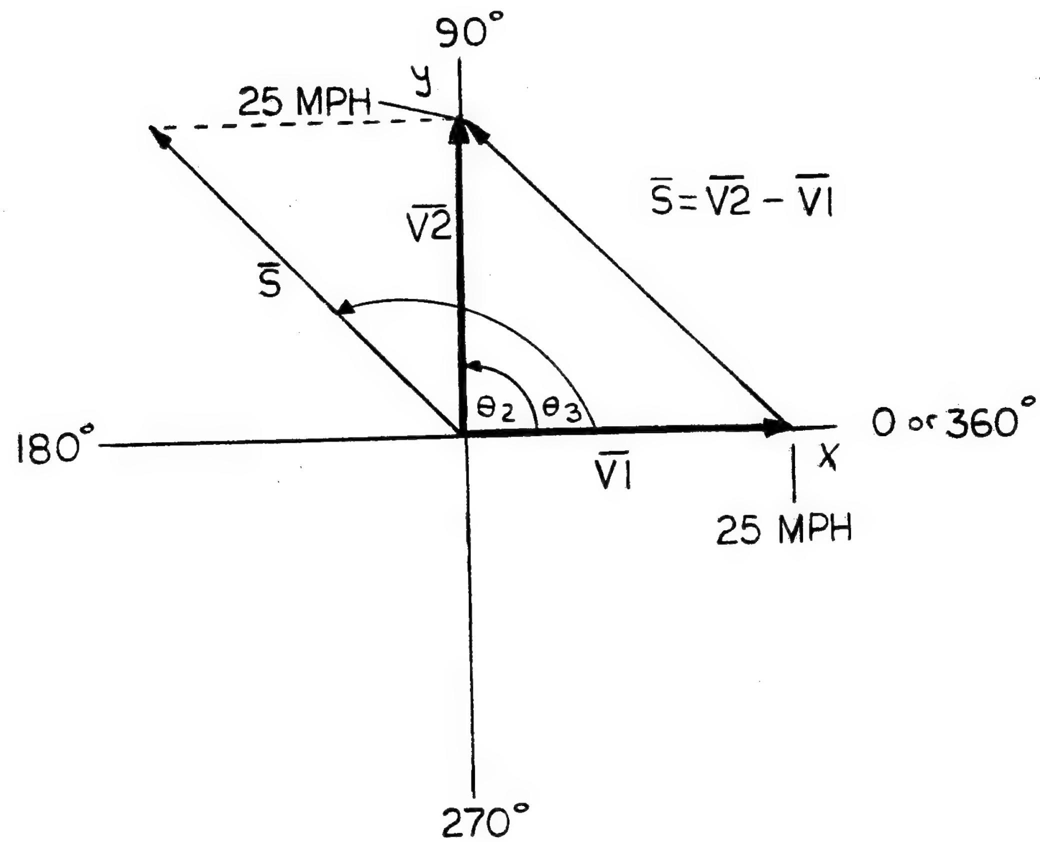


1 ———— = STRIATION ON BOTTOM OF BOAT 1

2 - - - - - - = STRIATION ON DECK OF BOAT 2

Striations Being Formed on Each Boat as Collision Progresses.
The Striations Were Made in the Direction from A to B.

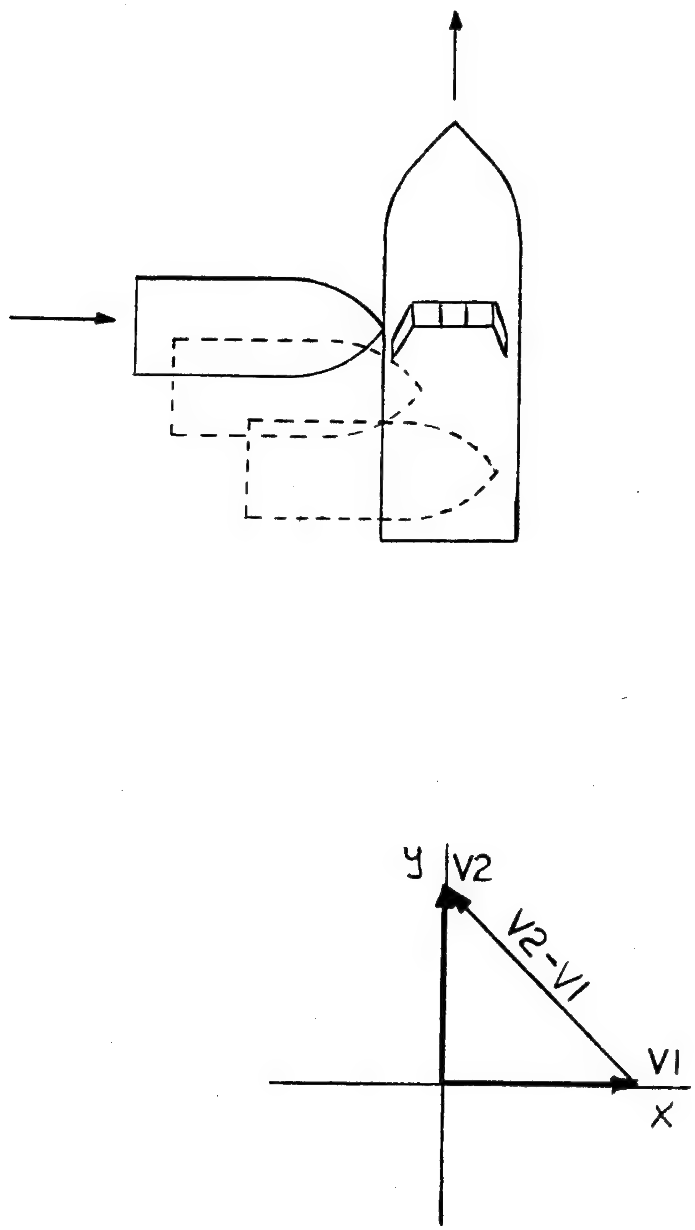
Figure 12-3



$\overline{V1}$ = Velocity Vector of Boat 1, Bullet Boat
$\overline{V2}$ = Velocity Vector of Boat 2, Target Boat
$\bar{S}$ = Striation Vector
$\theta 2$ = Angle of $\overline{V2}$
$\theta 3$ = Angle of $\bar{S}$

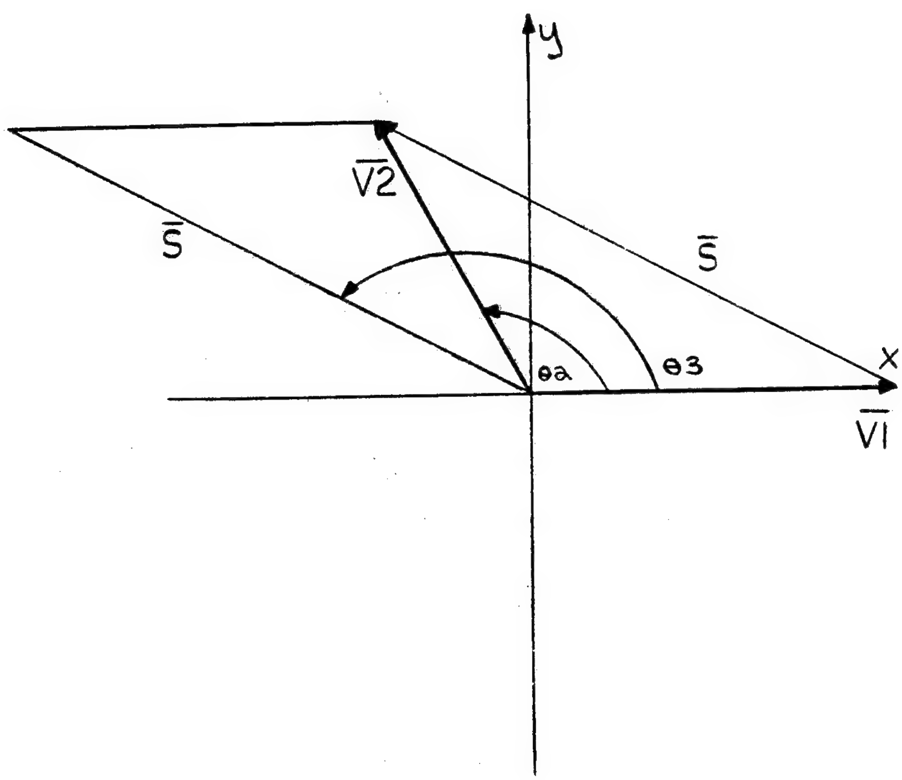
The Relationship Between Velocity Vectors and Striation Vectors.

Figure 12-4



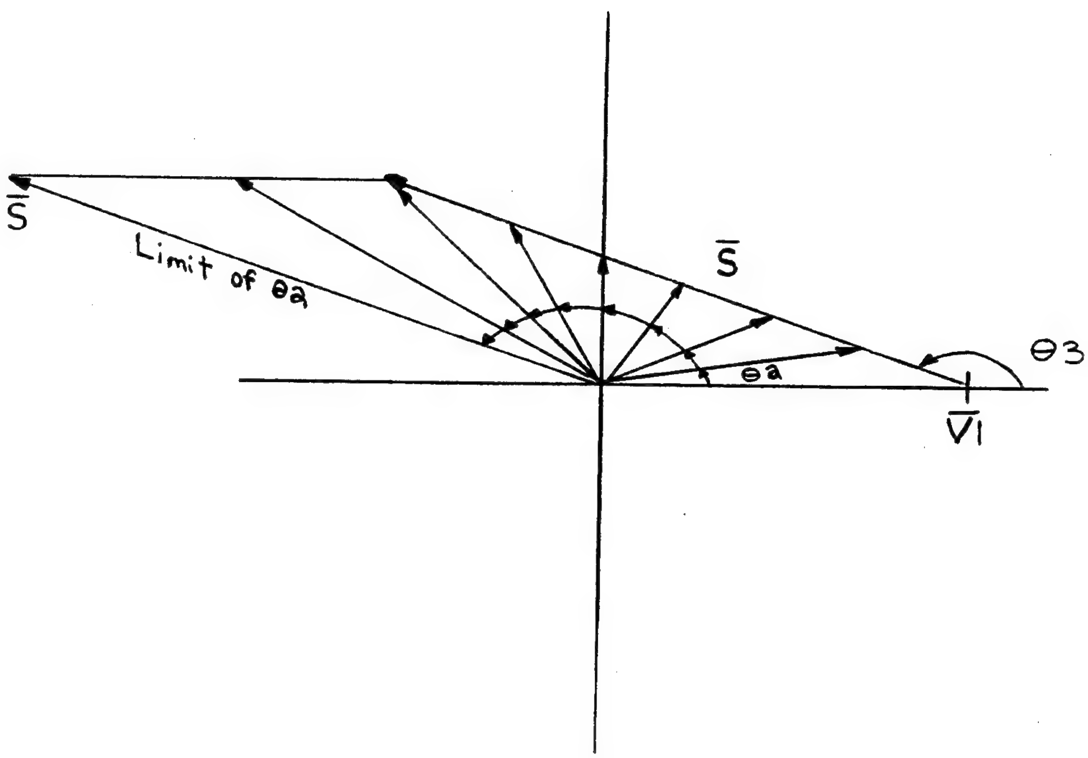
The Direction of the Striation Marks Indicates the Relative Motion of Two Boats During an Over-Ride.

Figure 12-5



A Velocity Vector Diagram Showing the Terminology Used in Striation Analysis.

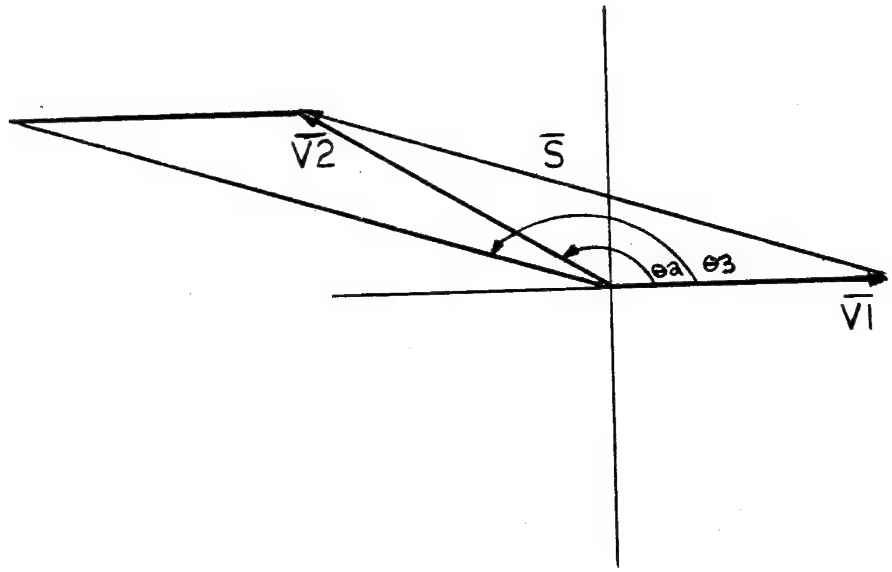
Figure 12-6



For Any Given Value of $\bar{S}$, There are a Variety of Angles of $\overline{V2}$ ($\theta 2$) That Could Result in the Observed Striation Marks.

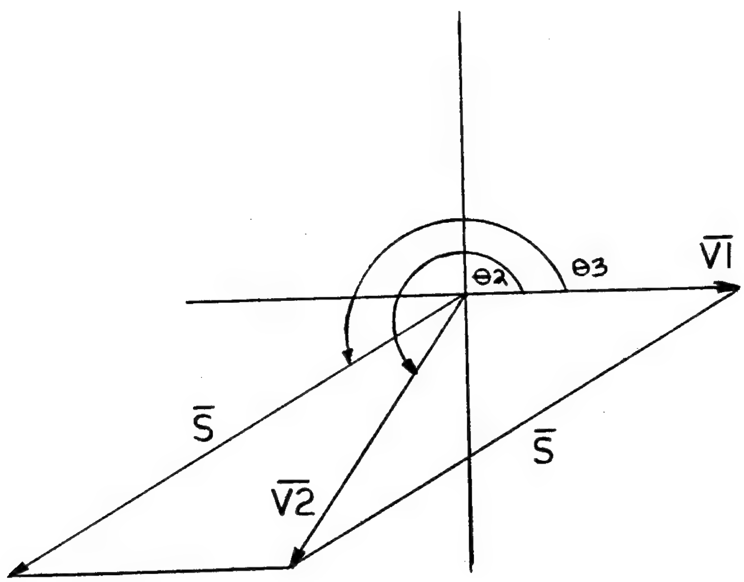
Figure 12-7

For $\theta 3$ Between 0 and 180°
$0 < \theta 2 < \theta 3$



(A)

For $\theta 3$ Between 180 and 360°
$\theta 3 < \theta 2 < 360$



(B)

Velocity Diagrams

Figure 12-8

This graph shows the Velocity Ratio of V2/V1 for a given striation angle of 25 degrees, while allowing the estimate of the impact angle θ2 to vary from 1 to 24 degrees. Note that as the value of θ2 approaches θ3, the VR becomes more sensitive to small changes in θ2.

$V2_i$ = VR	$\theta 2_i$
1.039	1
1.082	2
1.128	3
1.179	4
1.236	5
1.298	6
1.368	7
1.445	8
1.533	9
1.633	10
1.747	11
1.879	12
2.033	13
2.215	14
2.434	15
2.702	16
3.037	17
3.468	18
4.043	19
4.849	20
6.058	21
8.075	22
12.11	23
24.215	24

VR =

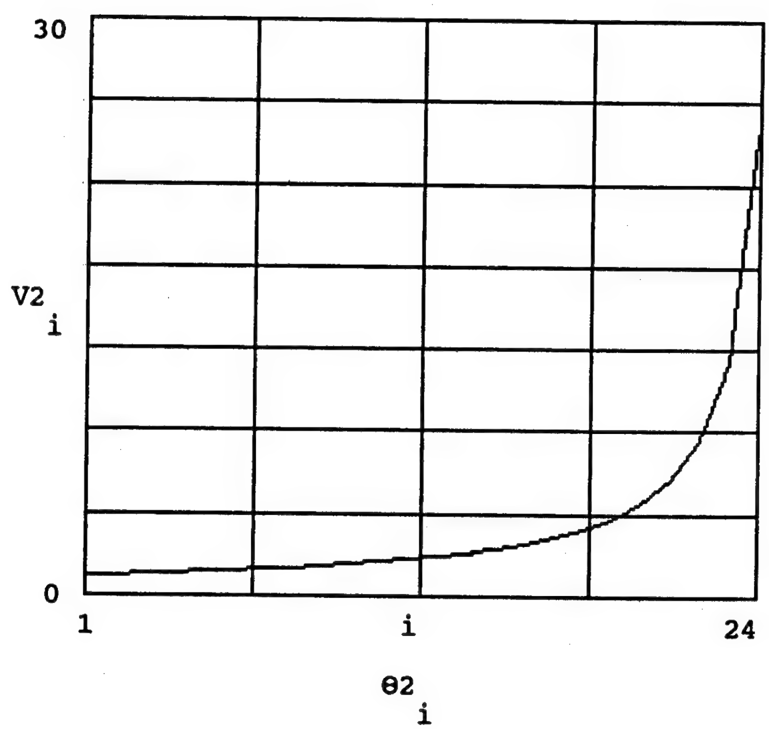


Figure 12-9

This graph shows the characteristic shape of the Velocity Ratio Equation. We have calculated a VR for all possible values of θ2 (the angle of the velocity vector of boat 2). This particular graph is for θ3 = 30 degrees. Remember that θ3 is the angle of the striation marks. This graph also represents θ3 = 210 degrees. It was plotted using equation 12-7.

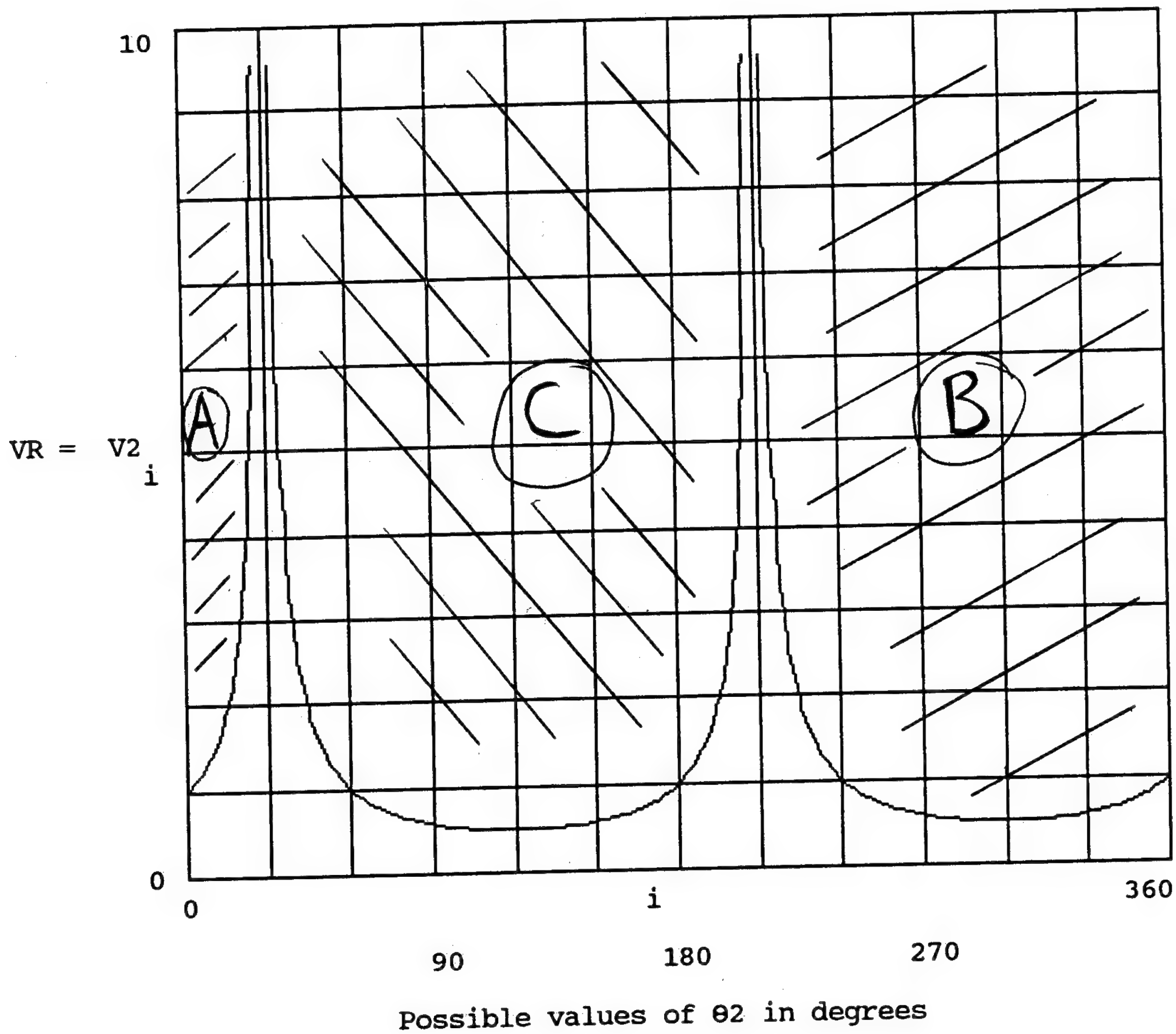


Figure 12-10

This graph shows the characteristic shape of the Velocity Ratio Equation for θ3 = 5 degrees, and 185 degrees. We have calculated a VR for all possible values of θ2 (the angle of the velocity vector of boat 2). Remember that θ3 is the angle of the striation marks. This graph is flatter at the bottom than the one if Figure 12-10.

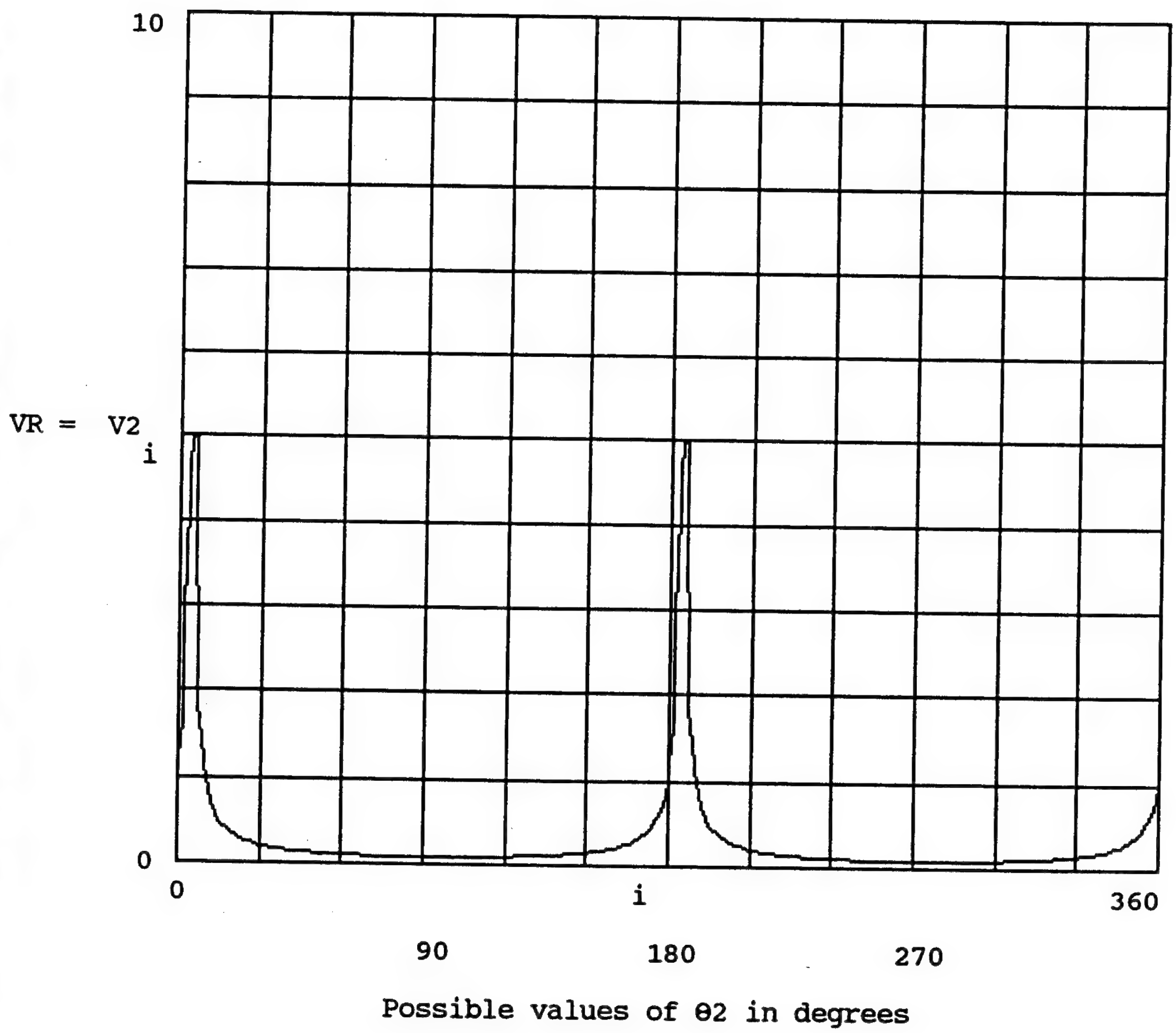


Figure 12-11

This graph shows the characteristic shape of the Velocity Ratio Equation for θ3 = 45 degrees and 225 degrees. It is much narrower at the base than the graph in Figure 12-11 or Figure 12-10 and has a different minimum value for the VR. Remember that θ3 is the angle of the striation marks.

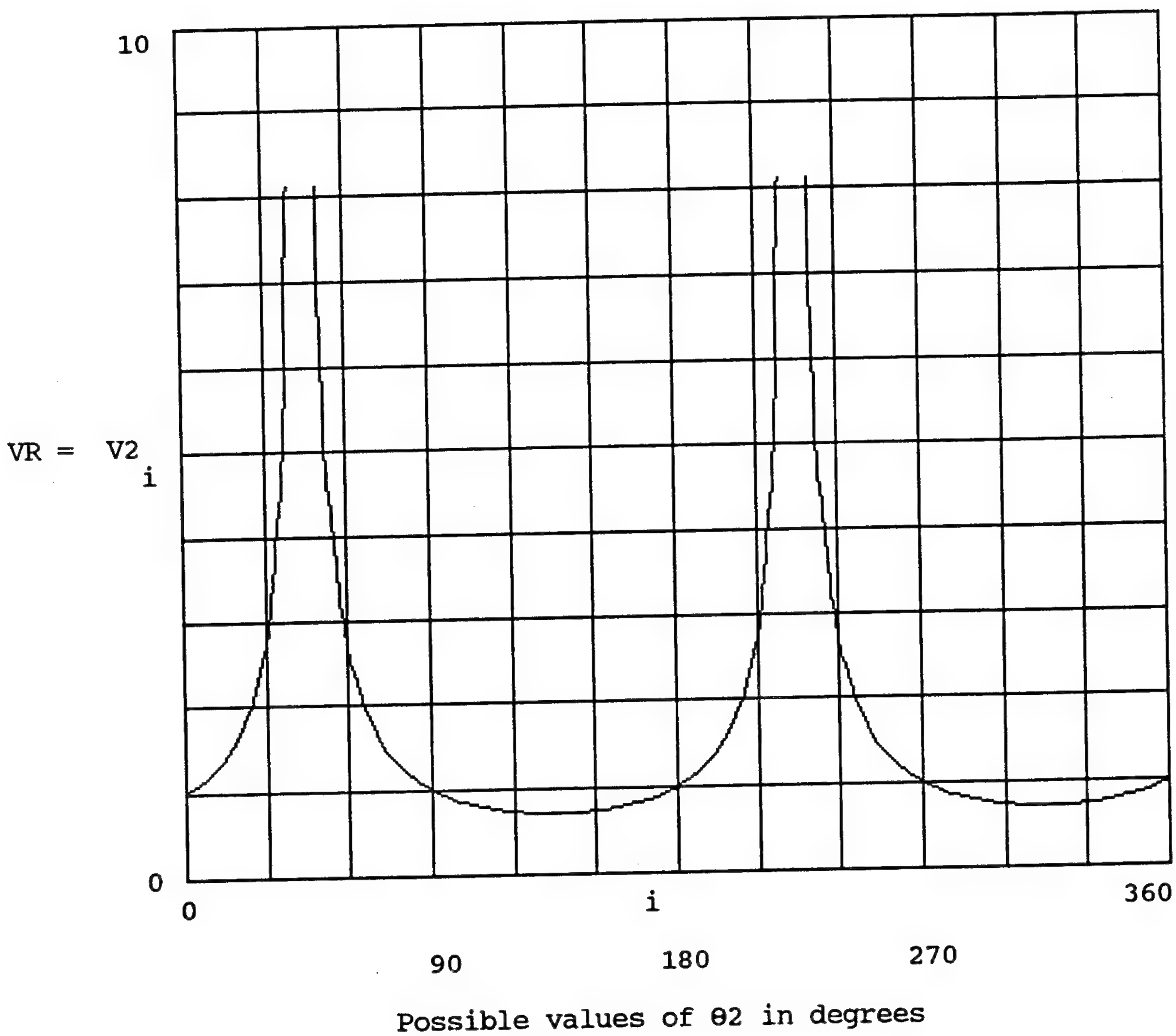


Figure 12-12

This graph shows the characteristic shape of the Velocity Ratio Equation for θ3 = 85 degrees and 265 degrees. The minimum VR now approaches 1. We have calculated a VR for all possible values of θ2 (the angle of the velocity vector of boat 2). Remember that θ3 is the angle of the striation marks.

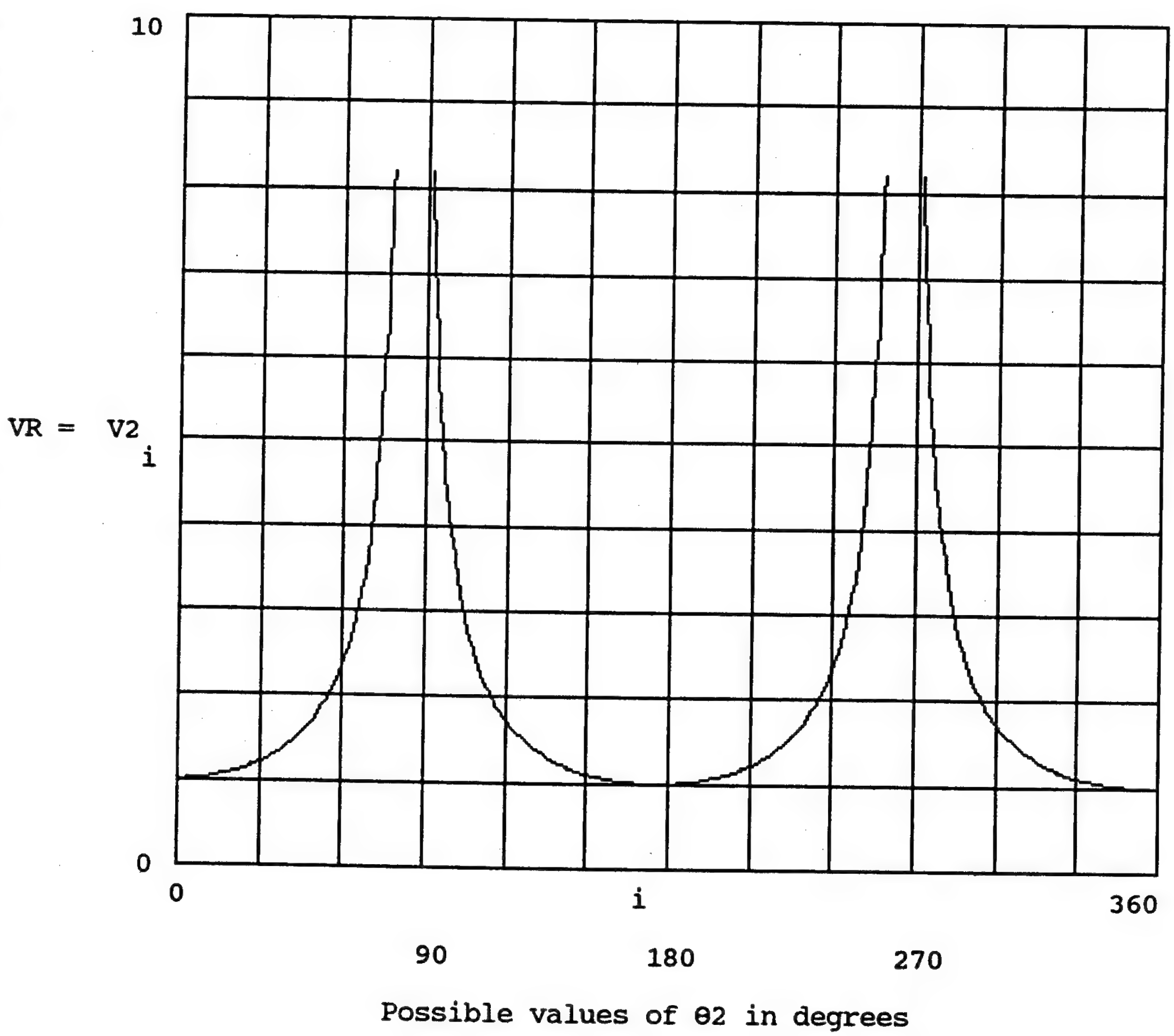
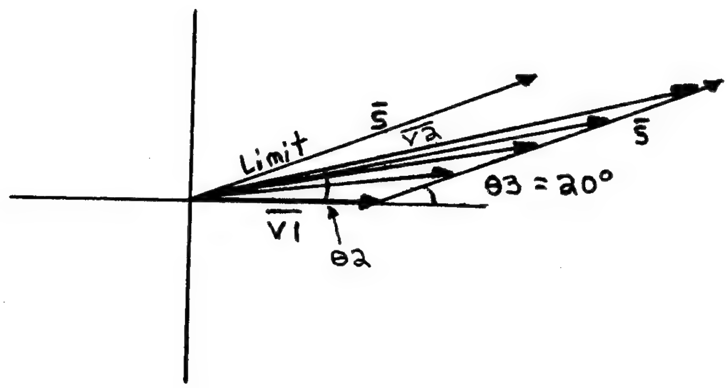


Figure 12-13

The series of diagrams that follow illustrate how to determine the minimum values of the VR for varying values of $\theta 3$ (the striation angle).

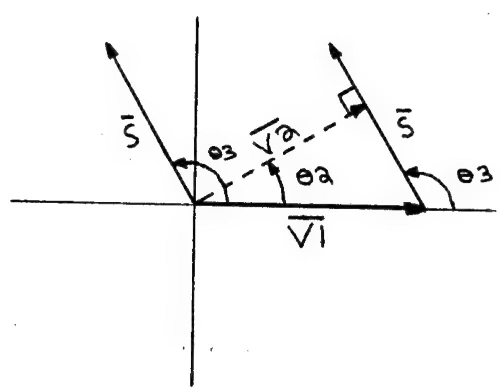
For $0 < \theta 3 \leq 90$:



The minimum VR is equal to one.
Note that $0 < \theta 2 < \theta 3$ for this range of $\theta 3$, and $0 < \theta 2 < 90$.
The minimum VR is undefined when $\theta 3$ = zero.

Figure 12-14(a)

For $90 < \theta 3 < 180$:

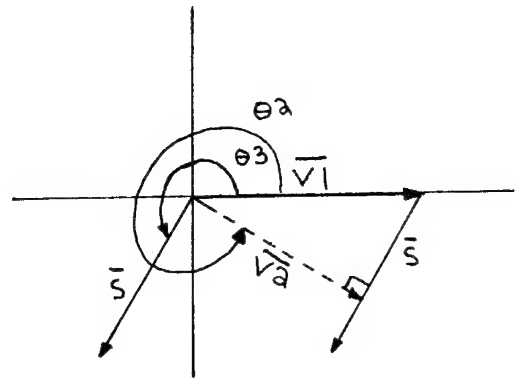


The minimum VR occurs when $\theta 3 = \theta 2 + 90$.
The minimum value of VR approaches zero as $\theta 3$ approaches 180.
Note that $0 < \theta 2 < \theta 3$ for this range of $\theta 3$, and $0 < \theta 2 < 180$.
The minimum VR is undefined when $\theta 3 = 180$.

Minimum Values of the Velocity Ratio (VR) for $\theta 3$

Figure 12-14(b)

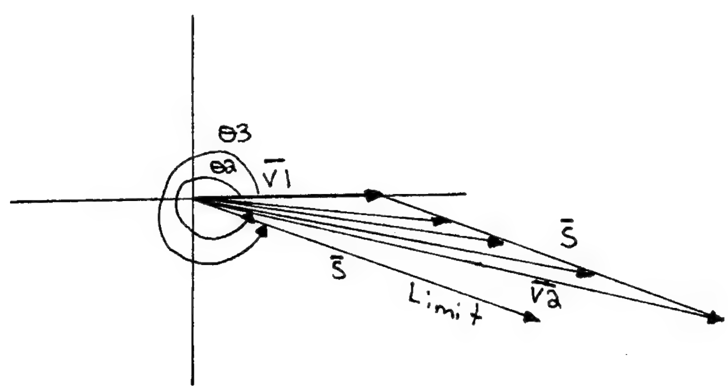
For 180 < $\theta 3$ < 270:



The minimum VR occurs when $\theta 3 = \theta 2 - 90$.
The minimum value of VR approaches one as $\theta 3$ approaches 270.
Note that $\theta 3 < \theta 2 < 360$ for this range of $\theta 3$, and $180 < \theta 2 < 360$.
The minimum VR is equal to one when $\theta 3 = 270$.

Figure 12-14(c)

For $270 \leq \theta 3 < 360$:



The minimum VR is equal to one.
Note that $\theta 3 < \theta 2 < 360$ for this range of $\theta 3$, and $270 < \theta 2 < 360$.
The minimum VR is undefined when $\theta 3 = 360$.

Minimum Values of the Velocity Ratio (VR) for $\theta 3$ (continued)

Figure 12-14(d)

This graph plots the minimum possible value of the VR for values of θ3 (the striation angle) ranging from 0 to 360 degrees. The minimum values for the VR must be between 0 and 1.

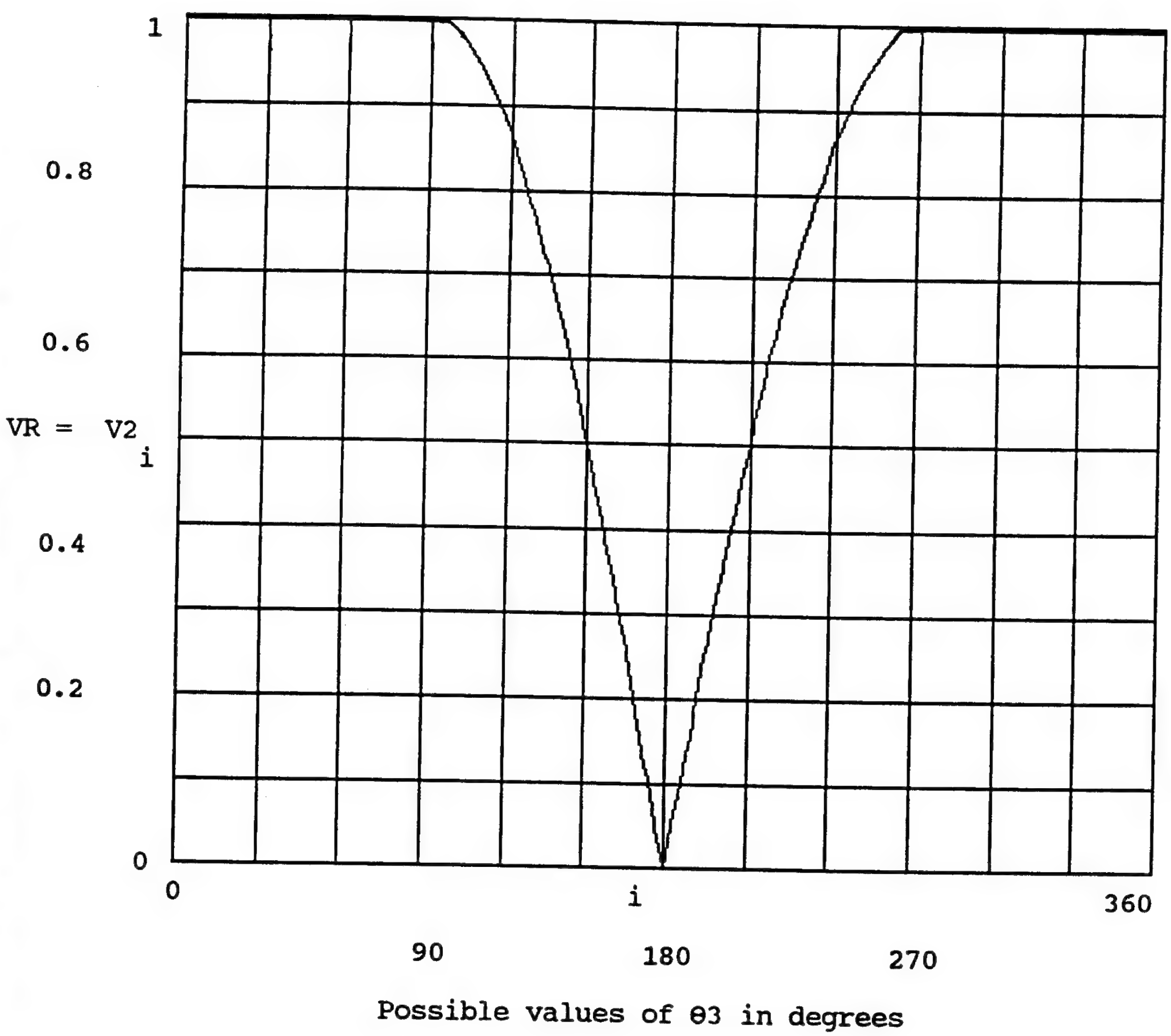


Figure 12-15

Minimum values of VR for $\theta 3$ between 90 and 180 degrees, and the corresponding values of $\theta 2$. Note that for these values of $\theta 3$ that $\theta 2 = \theta 3 - 90$ degrees.

$\theta3_i$	$\theta2_i$	$V2_i$
90	0	1
91	1	1
92	2	0.999
93	3	0.999
94	4	0.998
95	5	0.996
96	6	0.995
97	7	0.993
98	8	0.99
99	9	0.988
100	10	0.985
101	11	0.982
102	12	0.978
103	13	0.974
104	14	0.97
105	15	0.966
106	16	0.961
107	17	0.956
108	18	0.951
109	19	0.946
110	20	0.94
111	21	0.934
112	22	0.927
113	23	0.921
114	24	0.914
115	25	0.906
116	26	0.899
117	27	0.891
118	28	0.883
119	29	0.875
120	30	0.866
121	31	0.857
122	32	0.848
123	33	0.839
124	34	0.829
125	35	0.819
126	36	0.809
127	37	0.799
128	38	0.788
129	39	0.777
130	40	0.766
131	41	0.755
132	42	0.743
133	43	0.731
134	44	0.719
135	45	0.707

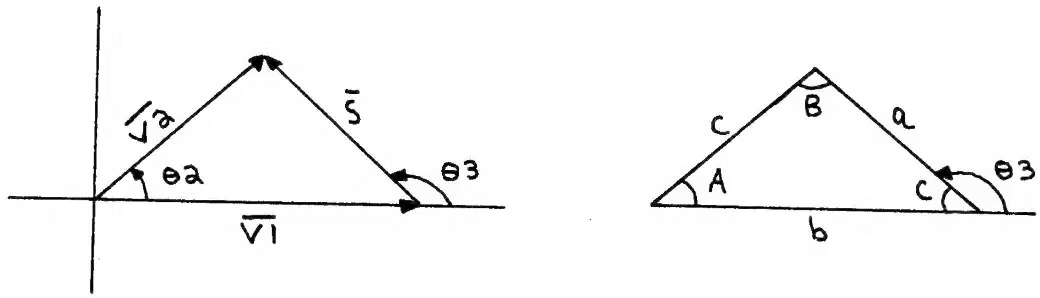
$\theta3_j$	$\theta2_j$	$V2_j$
136	46	0.695
137	47	0.682
138	48	0.669
139	49	0.656
140	50	0.643
141	51	0.629
142	52	0.616
143	53	0.602
144	54	0.588
145	55	0.574
146	56	0.559
147	57	0.545
148	58	0.53
149	59	0.515
150	60	0.5
151	61	0.485
152	62	0.469
153	63	0.454
154	64	0.438
155	65	0.423
156	66	0.407
157	67	0.391
158	68	0.375
159	69	0.358
160	70	0.342
161	71	0.326
162	72	0.309
163	73	0.292
164	74	0.276
165	75	0.259
166	76	0.242
167	77	0.225
168	78	0.208
169	79	0.191
170	80	0.174
171	81	0.156
172	82	0.139
173	83	0.122
174	84	0.105
175	85	0.087
176	86	0.07
177	87	0.052
178	88	0.035
179	89	0.017
180	90	0

Figure 12-16(a)

Minimum values of VR for θ3 between 90 and 180 degrees, and the corresponding values of θ2. Note that for these values of θ3 that θ2 = θ3 + 90 degrees.

$\theta 3_i$	$\theta 2_i$	$V2_i$	$\theta 3_j$	$\theta 2_j$	$V2_j$
181	271	0.017	226	316	0.719
182	272	0.035	227	317	0.731
183	273	0.052	228	318	0.743
184	274	0.07	229	319	0.755
185	275	0.087	230	320	0.766
186	276	0.105	231	321	0.777
187	277	0.122	232	322	0.788
188	278	0.139	233	323	0.799
189	279	0.156	234	324	0.809
190	280	0.174	235	325	0.819
191	281	0.191	236	326	0.829
192	282	0.208	237	327	0.839
193	283	0.225	238	328	0.848
194	284	0.242	239	329	0.857
195	285	0.259	240	330	0.866
196	286	0.276	241	331	0.875
197	287	0.292	242	332	0.883
198	288	0.309	243	333	0.891
199	289	0.326	244	334	0.899
200	290	0.342	245	335	0.906
201	291	0.358	246	336	0.914
202	292	0.375	247	337	0.921
203	293	0.391	248	338	0.927
204	294	0.407	249	339	0.934
205	295	0.423	250	340	0.94
206	296	0.438	251	341	0.946
207	297	0.454	252	342	0.951
208	298	0.469	253	343	0.956
209	299	0.485	254	344	0.961
210	300	0.5	255	345	0.966
211	301	0.515	256	346	0.97
212	302	0.53	257	347	0.974
213	303	0.545	258	348	0.978
214	304	0.559	259	349	0.982
215	305	0.574	260	350	0.985
216	306	0.588	261	351	0.988
217	307	0.602	262	352	0.99
218	308	0.616	263	353	0.993
219	309	0.629	264	354	0.995
220	310	0.643	265	355	0.996
221	311	0.656	266	356	0.998
222	312	0.669	267	357	0.999
223	313	0.682	268	358	0.999
224	314	0.695	269	359	1
225	315	0.707	270	360	1

Figure 12-16(b)



From the diagrams above, find the correlation between the angles A, B, and C, and the angles $\theta 2$ and $\theta 3$.

Find A:
A = $\theta 2$, by observation

Find C:
C = 180 - $\theta 3$

Find B:
A + B + C = 180

substitute the values above for A and C:
$[\theta 2] + B + [180 - \theta 3] = 180$
$B = 180 - \theta 2 - (180 - \theta 3)$
$B = \theta 3 - \theta 2$

Note that side ***b*** corresponds to V1, and has a value of 1.
Note that side ***c*** corresponds to V2, and side ***a*** corresponds to S (the striation vector).

From the Law of Sines:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

We really need to determine the length of side ***c***, which is equivalent to V2. Remember that since V1 = 1 by convention, that V2/V1 = V2/1 = V2 = VR.

Now substitute the values for B and C into the Law of Sines equation:

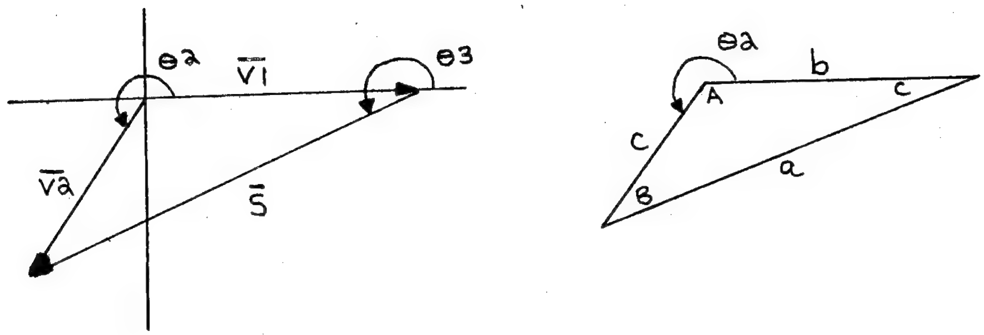
$$\frac{c}{\sin C} = \frac{b}{\sin B}$$

$$\frac{V2}{\sin(180-\theta 3)} = \frac{1}{\sin(\theta 3-\theta 2)}$$

$$V2 = VR = \frac{\sin(180-\theta 3)}{\sin(\theta 3-\theta 2)}$$

Geometric Derivation of the VR Equation
For 0 < $\theta 3$ < 180

Figure 12-17



From the diagrams above, find the correlation between the angles A, B, and C, and the angles $\theta 2$ and $\theta 3$.

Find C:
$C = \theta 3 - 180$

Find A:
$A = 360 - \theta 2$

substitute the values above for A and C:

Find B:

$$A + B + C = 180$$
$$B = 180 - A - C$$
$$B = 180 - [360 - \theta 2] - [\theta 3 - 180]$$
$$B = \theta 2 - \theta 3$$

Note that side ***b*** corresponds to V1, and has a value of 1.
Note that side ***c*** corresponds to V2, and side ***a*** corresponds to S (the striation vector).

From the Law of Sines:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

We really need to determine the length of side ***c***, which is equivalent to V2. Remember that since V1 = 1 by convention, that V2/V1 = V2/1 = V2 = VR.

Now substitute the values for B and C into the Law of Sines equation:

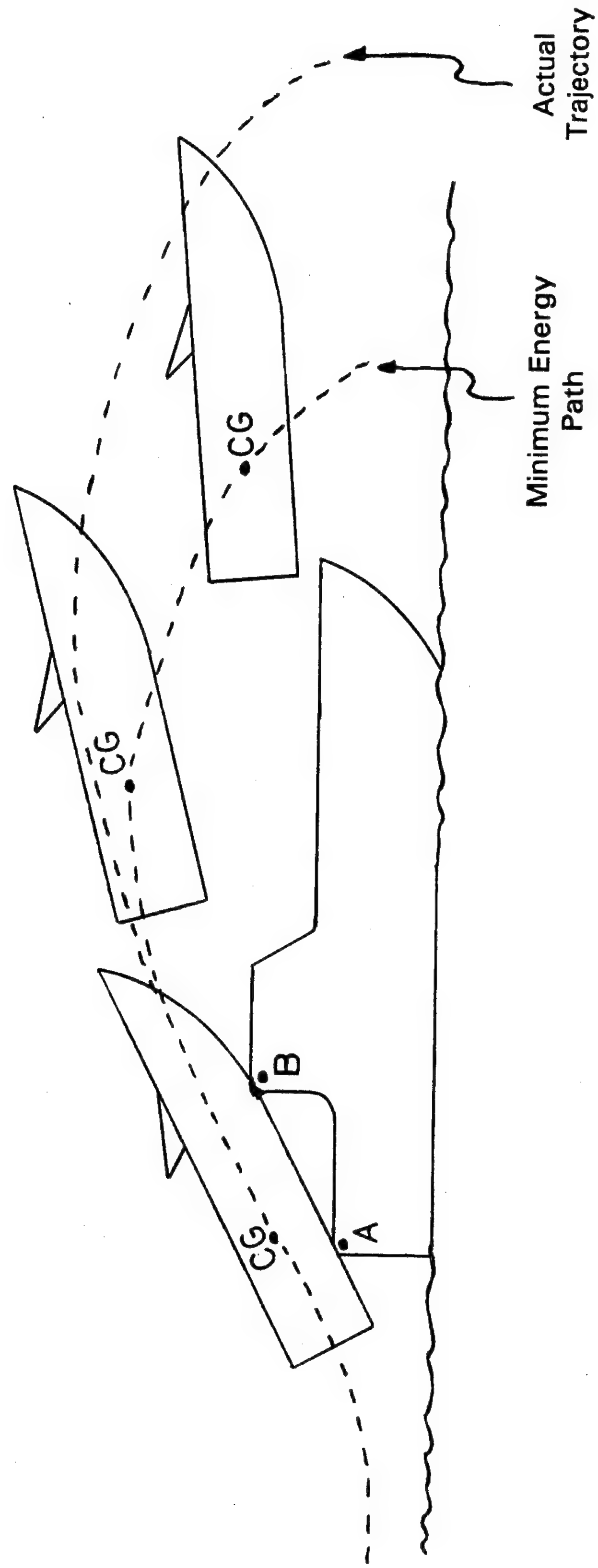
$$\frac{c}{\sin C} = \frac{b}{\sin B}$$

$$\frac{V2}{\sin(\theta 3-180)} = \frac{1}{\sin(\theta 2-\theta 3)}$$

$$V2 = VR = \frac{\sin(\theta 3-180)}{\sin(\theta 2-\theta 3)}$$

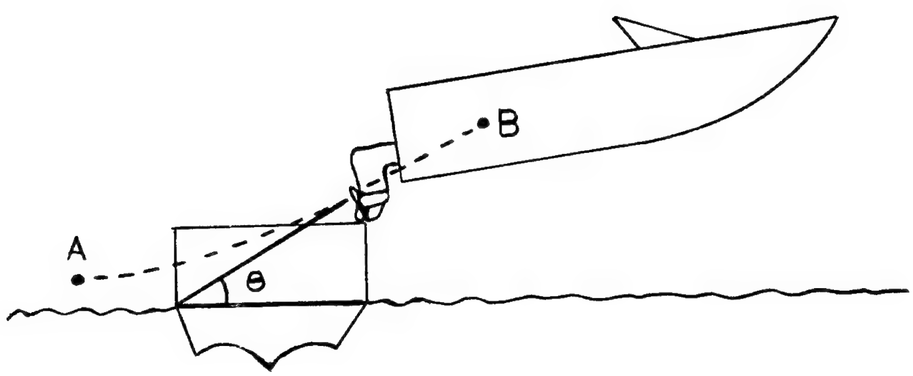
Geometric Derivation of the VR Equation
For 180 < $\theta 3$ < 360

Figure 12-18



The Trajectory for the Minimum Threshold Velocity.

Figure 12-19



Launch Angles may be Predictable Based on Collision Geometry.

Figure 12-20

CHAPTER 13

FIELD ACCIDENT CASE STUDIES

13.0 Introduction

The foundation for much of the data presented in this report concerning actual collisions is based on two important areas. The first area is data obtained from earlier experimental collisions which were conducted by UL in conjunction with the Florida Marine Patrol. These collisions were conducted before the beginning of work conducted under this USCG grant. These collisions were conducted primarily as training exercises. Funds and resources were not available to provide instrumentation on the boats at that time. Video data was obtained which provided an overall perspective of certain trends and tendencies. The second area from which much of the data was developed was from studies of field accidents of actual collisions. This chapter will discuss the field studies in more detail.

The field accident case studies were important for many reasons. These studies provided the researchers with a first hand look atthe problems faced by marine law enforcement officers, who are usually the ones called upon to investigate boating collision accidents. The procedures which were developed for collecting and analyzing data were based largely on the experience gained during the case studies of the field accidents. A study of the aftermath of real accidents was essential to ensure that any theories or methods of reconstruction were based on realistic data and situations. The field studies were a valuable learning tool.

Most of the analytical techniques and explanations regarding collision accident reconstruction are explained in various chapters and sections in this report. The purpose of this chapter is not to provide an example of how to write up investigative reports. To present a detailed reconstruction for every accident would repeat much of the earlier material presented. Instead, each accident case study will contain an overview, and a discussion of the evidence or other data which was unique and valuable for that particular accident.

The study of the field accidents helps to illustrate the magnitude of the problem of boat accident reconstruction. Several years ago, when the subject of boat accident reconstruction was fairly new, it was thought by some that the directions of impact and the general picture of what happened was usually obvious by examining the damaged boats. It was thought by many that the only real unknown was the estimated speed of the boats involved. The case studies of the field accidents revealed how complex it can be to determine, even in general terms, what happened. In more than one accident, at least two distinctly different scenarios were

thought possible. Even after careful and detailed analysis, it was not always possible to conclusively prove which scenario was correct. It was a humbling reminder that much work remains to be done before all accident scenarios can be reconstructed.

This chapter, and indeed much of this report, is unique in that we have attempted to apply scientific and engineering principles to phenomenon on which we have little data. To date, no experimental collisions have been conducted in which both boats were moving. We have been forced to make certain assumptions about the dynamic behavior of the boats involved, which future collision testing may or may not prove to be valid. It is with this in mind that we offer the hypotheses presented in this chapter regarding accident dynamics and reconstruction. Caution is encouraged in any accidents in which the methods developed in this chapter are applied, unless additional supporting data is available. Hopefully, future research and continued testing will someday allow the development of proven and reliable reconstruction methods.

13.1 Scope

Any collision which involved one or more recreational boats and resulted in severe property damage or serious injuries was a potential accident for study.

13.2 Purpose

The overall purpose of conducting the field accident studies was to obtain first hand information on boating collisions. The specific purposes for conducting the field accident studies were to:

a. Identify types or specific pieces of evidence which are common to each accident that can provide useful information.

b. Determine the best techniques for documenting each particular type of damage or other evidence so that the most information possible can be documented in a short period of time.

c. Determine the problems that accident investigators must face. This was done to help ensure that practical solutions were developed which took into account real-life difficulties.

d. Develop a checklist for use by the accident investigator to help ensure that the most critical items concerning the physical evidence of the collision have been documented.

e. Determine the adequacy of the current accident report forms. Provide input and areas for consideration for the possible revision of existing forms or the creation of new ones.

13.3 Method

UL received excellent cooperation from a number of different states which agreed to contact us when an accident fitting our criteria occurred. Once the states had completed their investigation, a UL engineer traveled to the accident site. The primary emphasis was placed on obtaining data from the boats involved. Any supplemental data already obtained by the state, such as photographs and accident reports, were used to assist in the study of the accident when available. When it was feasible, and relevant to the collision, a trip to the accident site was made.

The specific methods used to document various types of information varied from one accident to the next. The methods used on the later accidents were greatly improved over those used on the first accidents. The procedures described in the previous chapter are the combined result of the lessons learned from all of the field accident investigations.

13.4 Summary of Results

A total of ten collisions in eight different states were studied. Nine were actual accidents, while one was a staged collision which occurred between a barge and a motorboat. Nine of the accidents covered were Collisions With Another Vessel (CWAV), while only one was a Collision With a Fixed Object (CWFXO). None of the accidents were collisions with a floating object. A brief summary of the ten accidents is provided below:

1. Collision between two bass boats. Both boats were approximately 18 feet in length and were moving at significant speeds. Two fatalities.

2. Collision between a 23 foot cuddy cabin cruiser and 18 foot open motorboat. The cruiser was on plane and struck the 18 foot motorboat traveling at lower speed. Six were injured on the motorboat. No fatalities.

3. Collision of a 22 foot cuddy cabin cruiser with a steel channel marker. One fatality.

4. Collision of a 24 foot cuddy cabin cruiser with a steel barge. One fatality.

5. A barge struck an anchored 15 foot outboard boat. This collision was a staged collision conducted by the West Virginia Department of Natural Resources.

6. A 21 foot cuddy cabin cruiser impacted an 18 foot bass boat. Both boats were traveling at moderate speeds. Three fatalities.

7. A 20 foot open motorboat impacted a 20 foot stationary cuddy cabin cruiser from the rear. No fatalities.

8. A 19 foot open motorboat traveling at idle speed was struck from the rear by another vessel. No fatalities.

9. A 20 foot open motorboat struck a pontoon boat. Two fatalities.

10. A 19 foot open motorboat was impacted by a second boat of unknown size which sank following the accident. No fatalities.

13.5 Field Accident Analyses

For each collision studied, we will point out the most important information unique to that accident which was critical in its reconstruction.

Analysis Goals

The specific goals of the analysis for all Collisions With Another Vessel (CWAV), were primarily to determine the following items:

1. Initial impact point
2. Impact angle
3. The speed of each boat
4. Analyze occupant motions when possible

For all Collision With Fixed Object Accidents (CWFXO), the goal was to determine, to the extent possible what occurred, elaborating on any specific important events.

13.5.1 Accident Number 1:

13.5.1.1 Abstract

Two bass boats, both approximately 19 feet long, collided with each other. Both boats were on plane at the time of the collision. The bullet boat struck the target boat on the port side, about half way back from the bow. According to one witness, the boats were headed toward each other, and somehow the target boat swerved into the path of the bullet boat.

The bullet boat had six people on board. Four were injured and all but one were thrown overboard. One of the passengers sitting in the floor near the front of the boat reported being launched up into the air.

The target boat had four occupants on board. Of these four, two were killed and one was injured. The two fatalities were probably a result of being struck by the hull of the bullet boat.

Method Summary

The damage on each boat was gathered and documented. A scale diagram of each boat was made, and the damage locations were noted. The diagrams show the top view of each boat. This view is the best to utilize when estimating impact angles in an over-ride collision. The diagrams were first drawn to scale on graph paper and then the outlines and critical information traced onto a transparency. Analysis of both diagrams simultaneously was used to develop a range of estimated values for the impact angle, based on the methods described in Chapter 12.

13.5.1.2 Critical Data

Critical Data From Boat 1 (Bullet Boat)

The most important data obtained from the bullet boat was the striations which were left on the bottom of the forward half of the hull. Most of the striations were located on the starboard side of the bullet boat hull. A few small ones were located on the port side near the bow. Figure 13-1 and 13-2 show the striations. Since many of the striations were light, and would not show up on film, masking tape was placed next to the longer and deeper striations in order to ensure that the direction of these scratches was documented. The distance of the striations from the front of the boat was noted so that they could be properly located on a damage diagram. Figure 13-2 shows where two chunks of fiberglass were removed from the spray rails. This type of damage is typically caused when the bullet boat bottom catches a deck cleat, hand rail, or other hard metal object. Often the object on the target boat which caused this damage can be located and identified. It was especially significant that no striations could be found on the rear half of the bullet boat hull bottom. Figure 13-3 shows the striations as documented on the bullet boat.

A cleat located on the starboard side near the bow had fiberglass fragments wedged underneath it as shown in Figure 13-4. One piece of the fiberglass contained a color which was only found in a decal located on the rear of the other boat.

Critical Data From Boat 2 (Target Boat)

Figure 13-5 shows the target boat and the damage to the port side. Figure 13-6 shows the bullet boat, which suffered only relatively minor damage. Numerous small pieces of information were assembled to formulate a hypothesis for an impact angle. The damage diagram for the target boat is shown in Figure 13-7. In addition to the damage to the hull side, impact damage was noted on the steering wheel, the depth finder forward of the steering wheel, the passenger seat, and the top of the outboard motor housing. The depth finder seems to have experienced a glancing blow, while the steering wheel was impacted by something solid. Other components were damaged; however, those mentioned provided the best data for a reconstruction.

This boat had a decal near the gunwale toward the stern on both sides. The hull section where the decal was placed on the port side was missing; however, it was assumed that the decal placed on the starboard side was identical to the one that was missing. A similar undamaged boat was examined and found to have the same decals on both sides at the same locations. Parts of the missing decal were found wedged in a cleat in the bullet boat, which helped to establish the relative positions of the two boats during the collision.

A close look at the leading edge of the damage to the port side shows that the penetration angle of the hull side was at an angle, and not straight on. Note that this alone would not rule out an impact angle of 90 degrees; however, for this damage to occur, the target boat would have had to have significant speed when compared to the bullet boat. In other word, it is not possible to create this type of damage during a 90 degree impact if the target boat is stationary or moving very slowly.

Other Damage and Data

The hull surface of both boats was a metal flake paint, often silver in the damaged areas. Many of these areas contained stress cracks, which at first resembled striations from contact damage. Close examination revealed that the finish on the paint was actually untouched, and that the apparent striations were really stress cracks in the fiberglass. It is important to be sure not to confuse stress cracks with striations.

Damage to the bullet boat, shown in Figure 13-6, was relatively light. The hull appeared to have nearly severed from the deck cap, especially at the forward part of the boat. The hull had even cracked at the gunwale about half way back on the starboard side. This damage could have been caused by contact with the target boat during the collision. It could also have been caused another way. If the boat rolled severely to starboard while airborne, it could have landed on its side when it re-entered the water. This type of rolled attitude re-entry has been known to

cause separation of the hull and deck joints during earlier experimental collisions. Stress cracks all along the hull side may also be visible from extreme flexing of the hull side which also may occur during re-entry into the water. There was not sufficient information to determine if the boat rolled as a result of the collision.

The instruments on the target boat had interesting readings. The speedometer was stuck at 45 mph, and the tachometer was reading 2200 rpm. We were not able to remove the instruments for closer examination.

Occasionally, a speedometer or tachometer has been found to be stuck in a position other than zero after an accident. While this information is significant and important to record, we have not yet gained sufficient information on "stuck instruments" after an accident to determine the degree of reliability of their readings.

13.5.1.3 Analysis

Even without witness statements, several items were apparent from examining the damage.

1. The bullet boat went over at least a part of the target boat.
2. The bullet boat impacted the port side of the target boat.
3. The target boat was moving.

The conclusion that the target boat was moving is based on the striations found on the bottom of the bullet boat. The striations are at angle to the centerline of the bullet boat, which based on the discussion found in Chapter 12, is an indication that the target boat was moving.

The damage diagrams of both boats were analyzed to estimate the impact angle. Estimates of a range of likely impact angles were developed. The range was estimated to be between 101 and 123 degrees, using the techniques described in Chapter 12, Section 3.

The velocity ratio (VR) of the two boats, V2/V1 was developed for varying values of the striation angle and the impact angle. The ratio of V2/V1 is defined as the Velocity Ratio (VR) of the two boats involved. Figures 13-8, 13-9 and 13-10 provide Velocity Ratio charts showing the sensitivity of the velocity ratio (V2/V1) for values of $\theta 2$ of 101, 112 and 123 degrees respectively. The charts actually show the VR as V2. Remember since that V1 = 1 by convention, V2 = VR. These values are computed from the velocity ratio equation found in Chapter 12.

The estimation of the direction in which the target boat is traveling relative to the bullet boat is subjective at best. It is also difficult to measure accurately the striation angles on the bottom of the bullet boat. After all, it is only the component of the striations that lies in the horizontal plane that is relevant in the impact angle analysis. The information in the velocity ratio charts is important, not only to predict the magnitude of V2, but to determine how sensitive the velocity ratio is to slight errors in measurement.

In all three velocity ratio charts, we allow the striation angle (θ3) to vary from 130 to 150 degrees. This is the measured striation angle plus or minus approximately 10 degrees. Hopefully, striation measurements can generally be obtained with this accuracy or better. The charts show V2 on the vertical axis, and i on the horizontal axis. The value i is actually θ3.

What do the charts tell us? Look at Figure 13-8. If the value of θ3 is 139 degrees, then VR = V2/V1 = 1.066. This means that the magnitude of V2 was 1.066 times that of V1. Or stated another way, if the speed of boat 1 was 50 mph, then the speed of boat 2 was 50*1.066 or 53.3 mph. Remember that while the actual calculations may be quite precise, the numbers that go into them are only approximations at best. This technique should not be presumed to produce velocity ratios with great precision. These methods produce only approximations.

From looking at all three charts, we can develop a table that will tell us how accurate our guesses for the velocity ratio are likely to be. We will assume that the measured value of θ3 is 139 degrees, and allow for a tolerance of plus or minus 5 degrees.

Velocity Ratio Sensitivity

θ2	θ3	V2/V1
101	134	1.321
101	139	1.066
101	144	0.862
112	134	1.920
112	139	1.445
112	144	1.109
123	134	3.770
123	139	2.380
123	144	1.640

For the geometry of this particular collision, we can see that for larger values of θ2, our measurements must be highly accurate to produce accurate velocity ratios. The data above indicates that the velocity ratio is between 0.862 and 3.77 if we consider a range of impact angles between 101 and 123 degrees, and allow for a measurement error of the striation marks of plus or minus five degrees. In more practical terms, if the speed of the bullet boat (boat 1) was 40 mph, the speed of the target boat (boat 2) was between 34 and 151 mph! The range in this example is a result of

allowing both variables, $\theta 2$ and $\theta 3$, to vary by 10 degrees. Note that if the impact angle ($\theta 2$) were known with certainty to be 101 degrees, then the striation angle variance of 10 degrees would produce a narrower range of velocity ratios from 0.862 to 1.321. A more likely scenario is that the investigator can accurately measure the striation angles, and allow the impact angle to vary by 10 degrees in his estimate.

This brief example shows how critically important it is to properly measure the angle of the striation marks relative to the centerline of the boat. Just a few degrees can make a huge difference in the velocity ratio.

Even with the range in VR calculated above, we can see that boat 2 was traveling at a speed of at least 86% that of V1. This information can be useful if the target boat operator claims to have been sitting still.

During the collision, several events may have occurred which make it slightly more difficult to precisely pin down the speeds and impact angles.

The bullet boat may have rotated slightly counter-clockwise as the penetration progressed. The velocity of both the bullet boat and the target boat may have decreased slightly during the collision.

Figure 13-11 shows the most likely path of the bullet boat across the target boat. Note that the rear portion of the bullet boat never reaches the target boat. This means that the outdrive never penetrated the target boat in any region.

The initial impact point most likely was the leading edge of the damaged area on the target boat's port side. If we assume that this is correct, then we have a basis for further establishing an impact angle. We now have one more piece of information to help substantiate which of the values for $\theta 2$ is correct. For this particular accident, it is probably safe to assume that the bow of the bullet boat made first contact with the side of the target boat. While not totally conclusive, the damage diagrams show that it is possible that the bow of the bullet boat impacted the steering wheel, and the scratches on the port side of the bullet boat's bow were caused by impacting the depth finder. Remember that the striations on the bottom of the bullet boat's hull actually indicate the relative direction in which the bullet boat traveled across the top of the target boat. Look at the damage diagram for the target boat shown in Figure 13-7. If we draw a line from the initial impact point to the steering wheel, then we have a projected path for the bow of the bullet boat. Unless significant rotation of one or both boats occurred during contact, this line should be parallel with the striations on the bottom of the bullet boat. This exercise shows predisposition toward the impact angle ($\theta 2$) of 101 degrees. It is not conclusive however, because it would require a slightly greater impact angle for the last striations on the bottom of the hull of the bullet boat to make contact with the lower unit.

13.5.1.4 Summary

Witness statements initially estimated the speed of the bullet boat at approximately 25 mph and the target boat at 60 mph. This is a velocity ratio of V2/V1 of 2.4. From the VR charts, using the measured striation angle ($\theta 3$ = 139 degrees), we need a value for $\theta 2$ of 123 degrees (see Figure 13-10) to achieve a velocity ratio close to that. We see that these speeds are possible. If these speed estimates are accurate, it is also likely that the target boat would have been in a hard turn to starboard, which would have helped to create the consistency needed between the damage to the top of the outboard motor and the striations on the bottom of the bullet boat. This analysis also assumes an initial impact point on the target boat at the leading edge of the damage, approximately seven feet aft from the bow.

We were not able to perform this rather complex analysis while at the scene of the accident, which means that just like the rest of the real world, much information remains on the boats that is needed confirm this analysis. If it were possible to return to the damaged boats, closer examination of the steering wheel on the target boat should pinpoint what part of the bullet boat made contact. It should also be possible to place the target boat on a trailer, and rotate the engine and steering wheel into the position in which they were located at impact. This would establish if the target boat was in a turn or headed straight at the time of the collision. During our examination, both boats were sitting on the ground. This prevented our researchers from getting a good look at the entire bottom of the hull of the bullet boat. Critical information may have been sitting in the mud! This was another lesson in how important it is to have complete access to the boats involved, and to hang on to them until the analysis is completed!

13.5.2 Accident No. 2:

13.5.2.1 Abstract

A 23 foot cuddy cabin cruiser impacted a 19 foot open ski boat. The cruiser struck the ski boat on the starboard bow, and rode up on top of the ski boat. The cruiser stopped with its aft end partially resting on the stern of the ski boat. Six occupants in the ski boat were injured, but none were killed in the collision. The cruiser contained two occupants and neither one was hurt seriously.

Witness statements claimed that the ski boat was barely moving, perhaps cruising at idle speed. The operator of the cruiser stated he was on plane, but slowed just before impact, and even had time to think to raise the lower unit on his I/O as it was sliding across the ski boat.

The accident happened near shore, and both boats rested in shallow water among a group of mangroves. The mangroves caused additional damage to the boats, especially to the cruiser. Figures 13-12 and 13-13 show overall views of the cruiser and ski boat respectively.

Method Summary

Damage from both boats was documented and photographed for later reference. Damage diagrams for both boats were created using the same techniques as described in Accident No. 1. The accident diagrams and photographs were analyzed carefully. A striation analysis was developed to provide guidance in determining the possibility of various scenarios. Methods described in chapter 12 were used for the documentation process.

13.5.2.2 Critical Data

Critical Data from Boat 1

Boat 1, the bullet boat, was a 23 foot I/O cuddy cabin cruiser. The most noticeable damage to the cruiser besides that caused by the trees it brushed against was a series of colorful striations on the port bow. These marks were unusual since they appeared to be nearly vertical. The coloring of the markings matched the colors in the decal of the struck boat. These markings were not just along the edge of the hull near the bow, but extended back for approximately 18 inches.

Virtually all of the striations and noticeable damage to the cruiser on the bottom was on the port side. Several different sets of striations were located and documented on the bottom of the hull.

The bow eye on the cruiser was bent noticeably to starboard. Striations were also noted around the bow eye with the same coloring as the coloring on the struck boat.

The chine along the port side suffered severe scraping for a distance of two feet, beginning about five feet from the stern and extending until approximately seven feet from the stern. The scraping was indicative of fiberglass which has rubbed across a metal surface.

The outdrive incurred a significant chip in the leading edge of the lower unit, and part of the bracketry was fractured. More damage was visible on the port side of the outdrive than the starboard side. Photos and documentation of these items proved to be very important in the analysis.

In the interior of the cruiser, a small table mounted on a single post had broken. The heavy table top was mounted on a single post, which had given way at its mountings in the floor at impact. The angle at which the post was leaning was a possible indicator of the principal direction of force and possibly the impact angle.

Upon impact, the operator was thrown forward and to port. In fact, he struck the companionway doors which closed off the cuddy cabin. His direction of travel in the boat was roughly parallel to the direction in which the table post was leaning.

Of special value in this accident were photos taken of the two craft at the accident scene. The photos showed that the cruiser was indeed partially resting on the ski boat. The photographs were valuable because they showed the final rest positions and the trees which were impacted. It was also apparent from the photos that one or both boats may have been touching the bottom in their final rest positions.

Critical Data From Boat 2

The condition of the target boat following the collision "was a mess" to put it in non-technical terms. The hull sides, console, windshield, seats, and railings had all been ripped from their normal positions and thrown toward the aft port quarter of the boat.

The starboard bow was badly damaged. A large vee shaped cut was carved into the hull. The forward edge of the vee shaped cut-out was a notch shaped cut as shown in Figure 13-14. This notch was believed to have been from penetration of the bow hook on the bullet boat.

Damage to the starboard rear quarter near the stern as shown in Figure 13-15 may have been the area where the outdrive impacted; however, investigators informed UL that rescuers on the scene had to literally cut part of the ski boat out of the way in order to get to occupants trapped in the wreckage. Without knowing any more details of what was cut away, it was difficult to distinguish between impact damage and damage caused by the rescuers. The most forward edge of the area of the corner appears as though it may have been impact damage. The horizontal cuts adjacent to it are much cleaner as though a saw had been used.

13.5.2.3 Analysis

Initial Impact Point

The damaged area on the starboard bow of the target boat shown in Figure 13-13 is believed to be the initial impact area. The notch in the forward most part of the "V" shaped section is likely where the bow hook of the bullet boat passed through. Dimensions

of the hole, and the bow eye on the bullet boat were documented and analyzed. The notch is nearly identical in size to the bow eye on the bullet boat. Note that this notch is not vertical, but angled down and toward the bow. The bow eye on the bullet boat was bent to starboard, indicating that it had likely made contact with the hull. Striations on the bow of the bullet boat as shown in Figure 13-16, appeared to be nearly vertical when viewed with the boat on the trailer after the accident. These striations extended for 12 to 18 inches on the bow, still in the vertical direction. This indicates the entire area was in contact with the target boat at the same time. Figure 13-17, shows how the initial contact might have been possible to account for this damage. This theory is further supported by the shape of the notch. The shape of the notch's cut from the bow eye closely matches the profile, not the straight on view of the bow eye.

Estimated Speeds

Since the bullet boat remained partially on top of the target boat, it is likely that this was a moderate speed impact, as opposed to a high speed one. Based purely on subjective data gathered from earlier experimental collisions, the speed of the bullet boat was probably between 15 and 25 mph. In other words, 20 mph plus or minus five. Again, this is only an estimate. If the bow of the bullet boat had impacted the trees on the shoreline before clearing the target boat, the speed estimates could have been much higher!

A difficult question to answer is the speed of the target boat. Witnesses aboard the ski boat claimed that their boat was either sitting still or cruising at idle, and that the cruiser struck them nearly head on. The hypothesis was formulated that the ski boat was traveling forward at the time of impact. Several indicators are present to support this. For one, the clean notch in the bow of the ski boat would not have been visible if the ski boat had been sitting still. If the ski boat were stationary, the remainder of the bullet boat passing through that area would have wiped out the initial notch and "V" formed so neatly in the bow.

The striation marks on the bottom of the bullet boat also indicated that the target boat was moving. The nearly vertical markings on the bow of the bullet boat were only on the port side. The starboard side of the bow had no indications of any contact with the other vessel. The target boat would almost certainly have had to have some forward velocity to produce this effect.

Several different sets of striation marks were located on the bottom of the bullet boat hull. Almost all of them were on the port side of the hull bottom, and virtually no damage at all was found on the starboard side of the centerline on the hull bottom. The exception was some striations toward the stern which likely

occurred once the bullet boat had come to rest on top of the target boat. The clearest set of striation marks furthest forward on the hull bottom (on a relatively flat portion of the hull) was measured to be 35 degrees from the centerline. This translates into a striation vector of 215 degrees, as shown in Figures 13-18a and 13-18b.

Figure 13-19 shows the striations that were documented on the hull bottom of the bullet boat. Remember that the velocity of both boats went from their pre-impact speed down to zero by the time they came to rest. Once both boats had come to rest, there may have been shifting and rotation of the target boat. The photos taken at the scene showed the aft end of the bullet boat resting on the stern of the target boat. The centerline of the two boats appeared to be between 45 and 75 degrees apart. (These angles would correspond to velocity vector angles of 305 degrees and 335 degrees on the velocity diagram.) The water and winds were calm at the time of the accident, so it is possible that this angle is indicative of the impact angle. Obviously, this is not sufficient information on which to base an analysis, but it should be considered.

The damage to the chine was possibly caused by scraping along the side windshield frame. The object which did this damage was most likely metal with a sharp edge moving somewhat laterally to the chine. Whatever the impact angle, it should be such that this area of the chine made contact with the side windshield frame, or other hard metal object capable of creating this type of damage.

The operator of the bullet boat claimed to be in a hard turn to starboard at the time of impact. Striations along the bottom of the bullet boat as shown in Figure 13-19 were not all in the same direction. The forward most sets were clearly between 35 and 45 degrees to the centerline. This corresponds to striation vector angles of 215 and 225 degrees respectively. The aft sets of marks were at much greater angles, approaching 65 and 80 degrees relative to the centerline, which correspond to striation vector angles of 245 and 260 degrees respectively. No data is available to show conclusively what would have happened to the bullet boat if the impact had occurred while it was engaged in a hard turn to starboard. The possibility exist that the bullet boat may tend to start to rotate clockwise, with the stern sliding laterally more than the bow. This action would help to account for the variations in the striations toward the aft end of the bullet boat.

A striation analysis in this type of collision must be performed carefully. Numerous factors in this collision place the confidence level for this type of analysis lower than for most collisions. First, we already know that the velocity of both boats went from pre-impact speeds to zero during contact. This alone will cause variations in the striation angles unless both boats remain in a direction parallel to their initial contact, do not slide laterally (with respect to a fixed reference) and decrease their velocity in such a way that the velocity ratio, V2/V1 is maintained. This combination of events is highly unlikely! With these concerns in mind, we will proceed with a striation analysis. A good set of striations located fairly far forward on the bullet

boat can be used to provide an indication of the impact angles. This impact angle would be the angle between the centerlines of the two boats when the portion of the hull where the striations are located made contact. The striation angles could be affected by any rotation which may have already begun. The further forward the striations, the less severe this effect is likely to be for this scenario.

Consider the damage diagram in Figure 13-19. Based on a striation angle of 215 degrees, we will consider that the impact angle could have been anywhere between 216 degrees and 350 degrees (350 degrees would be nearly a head on collision). Figure 13-20 shows a plot of the velocity ratio for this range of angles.

The closer the impact angle is to the striation angles, the higher the velocity ratio. Analysis of the damage diagrams favored an impact angle between 254 and 300 degrees. Figure 13-21 shows the VR for impact angles from 240 to 320 degrees. This is simply a more detailed look at a portion of the graph shown in Figure 13-20. For an impact angle of 254 degrees, the VR is 0.911. Refer to Figure 13-22 and Figure 13-23 to see how these angles determined the damage done to the target boat. For an impact angle of 300 degrees, the velocity ratio is 0.576. Note that this value is closest to the lowest possible VR for these striations which is 0.574. Thus, the target boat was traveling at a speed of at least .57 times that of the bullet boat, assuming that our striation angle measurements are correct.

In this accident, both parties gave estimates of their boat's speed, which if accurate, would have established the VR for this collision. Figure 13-20 shows that there is a wide range in possible values for the impact angle that would result in little change in the VR. If the VR charts had shown a narrower range of impact angles for an estimated VR, an estimate of the actual impact angle could be obtained. This accident shows us that if an estimate of the VR were obtained based on witness statements, that the corresponding impact angles could be determined. The estimated impact angle may be fairly accurate if the collision geometry was such that the VR changed rapidly with only a slight change in the impact angles. Figure 13-10 is an example of a VR chart where the VR varies greatly with only a slight change in impact angle. While the velocity ratio diagrams for this accident do not help us provide a narrow range of estimates for the impact angle, they do help to establish a minimum VR of 0.574 that changes little throughout the range of possible impact angles. This information is especially useful since we are fairly certain that the bullet boat was on plane at the time of impact.

It is important to notice what is not damaged on the target boat. The windshield frame for the forward part of the side windshield on the port side of the target boat is still standing. This indicates that either the bullet boat went completely over the top of it that is went off to the side. Since the bullet boat was still partly resting on the target boat, it is reasonable to assume that it did not have sufficient velocity nor the proper heading to

have jumped over the windshield. You can see by examining Figures 13-22 and 13-23 that an impact angle closer to 254 degrees would have been more likely to miss the windshield frame on the port side.

13.5.2.4 Summary

Based on experience with past collisions, the bullet boat probably was traveling between 15 and 25 mph at impact. Based on a measured striation angle of 215 degrees, the absolute minimum velocity ratio is 0.574. Thus, the speed of the target boat would have been between 8 and 15 mph. If we consider the impact angle of 254 degrees and the corresponding VR of 0.911, the target boat would have been traveling between 13 and 23 mph, assuming the bullet boat speed was between 15 and 25 mph. Clearly at the higher end of this range, the target boat would have probably been on plane at impact.

We were not able to do so, but if specific data could be taken on the height of the bow above the water for both boats at various speeds, it may help to further establish the speed of each boat at impact. The target boat would likely have a bow high attitude at 15 mph. Determining if the target boat were at hump speed or still at displacement speed at time of impact would further reduce the range of estimated speeds for each boat. In any case, we can be fairly certain that the target boat was not sitting still at impact. It was probably traveling at least eight mph.

13.5.3 Accident No. 3:

13.5.3.1 Abstract

A 22 foot long V-hull I/O with a small cuddy cabin impacted a 12 inch steel I-Beam that was supporting a channel marker. An overall view of the undamaged side of the boat is shown in Figure 13-24. The accident occurred at night on a narrow channel. An operator and one passenger were on board. The boat was reportedly traveling at high speed when it hit the channel marker. The beam penetrated the starboard bow of the boat for a considerable distance. The passenger was thrown out of the boat at impact, and possibly struck the I-Beam. The passenger was fatally injured. The operator suffered only minor injuries and was believed to have been intoxicated at the time of the accident.

Witnesses on shore reported seeing the boat running around the channel in tight circles until it sank in shallow water. The boat was badly holed from the accident and sank soon after impact.

The channel marker struck by the boat was later found with the top of the I-Beam even with the water's surface. The tops of similar channel markers were an estimated 8 to 12 feet above the water. The markers, battery pack, and light normally attached to the marker post were missing. Apparently the boat had either bent

the channel marker during impact or simply pushed it over. The latter seems much more likely. One of the diagonally shaped pieces of plywood originally attached to the marker was later found washed up on shore.

13.5.3.2 Critical Damage to the Boat

The channel marker clearly demonstrated its superior strength in this battle of fiberglass versus half inch thick steel. The I-Beam penetrated the bow just beneath the hull deck joint about 2 feet to the right of the centerline. About four feet back from the bow, the top of the beam penetrated the foredeck. The beam penetrated the lower portions of the hull in a line much closer to the centerline of the boat. The beam penetrated the hull for a distance of approximately 11 feet, at which point it exited out of the starboard side of the boat rather abruptly. A view of damage done to the foredeck may be found in Figure 13-25. The portion of the hull where the beam exited is shown in Figure 13-26.

The propeller was badly damaged. The blade tips were flattened as if they had hit the steel I-Beam. The bottom of the hull had striations on the port side well away from the area where the I-Beam had penetrated.

The speedometer and tachometer were examined using an ultra-violet light for any signs of needle slap. None was found. The engine and equipment in the engine compartment was examined for any signs of slippage or movement in an attempt to ascertain the principle direction of force and gain possible estimates of the magnitude of deceleration. The engine had not shifted a discernible amount. Loose equipment in the engine compartment had shifted from its original position, but since the vessel sank, it was not possible to determine where things were just after impact.

13.5.3.3 Analysis

The purpose of this analysis was to answer the following questions:

1. What was the speed at impact?
2. Was the boat turning at impact?
3. What caused the inconsistent damage to the bottom of the boat and to the propeller?

<u>Speed Estimates</u>

There are two approaches that could be used to estimate the speed of this boat at impact. Unfortunately, both methods require data that is difficult to obtain. The first method depends on finding indicators inside the boat that can be used as an estimate of the deceleration rate of the boat. This could be as crude as needle slap on the speedometer, or a fixture, bracket, or bolt that

was broken due to dynamic forces. It would need to be an object that could be tested in a laboratory to determine the range of dynamic values required to create the failure. This method for estimating speed also depends on estimating the deceleration distance. If both of these items can be found, the formulas in Chapter 11 can be used to estimate the speed. It is important to realize that the values calculated by the formulas are average deceleration rates over the entire distance and that indicators may only fail under a peak acceleration. Consequently, the results must be interpreted accordingly.

We will take a brief look at how the speed estimate based on deceleration rates might have been performed. In spite of the thoughts that come to mind when visualizing a boat striking an I-Beam, this was probably not as much of a high-g deceleration as one might think. Whatever speed the boat was traveling, it had a rather long distance to decelerate. The deceleration distance included at least 10 to 12 feet that the beam was in contact with the boat, plus the distance that the post moved while being pushed over by the impact. Water depth measurements were not made, but Figure 13-27 shows how to estimate the distance that the I-Beam traveled while the boat was in contact. The diagram assumes that the beam was pushed over from the bottom and not bent somewhere in the middle.

Unfortunately, no indicators were located that would allow an estimation of the deceleration rates. If they had been, the deceleration rate, coupled with a deceleration distance could have provided a speed estimate. A possible second method of estimating speed is based on the amount of fiberglass sheered by the post.

Was the Boat Turning?

It seems like such a simple question. All of the data was carefully reviewed, and the results were inconclusive. The exact details of the structure struck would have to be known to answer the question with certainty. This data was not available for our analysis. The structure from a similar post could have been documented carefully, and the results based on that. Figure 13-28 shows the type of diagrams which would help to determine the sequence of events and answer many other questions regarding the details of the collision. This diagram shows how the actual orientation of the boat in relation to the post can be determined. The cross section of the hull should be carefully drawn to scale at one or more damage locations. Critical damage in the plane of the cross section should be noted. The outline of the channel marker should be drawn to the same scale on a transparency. Since the exact impact angle is not known, several different drawings of the marker should be made, perhaps from straight on at the marker, 45 degrees, and 90 degrees to begin. The transparency with the marker can then be placed in various hull cross section drawings until the damage patterns match. This type of analysis is still difficult because the shape and orientation of the marker changes as the collision progresses. This procedure would probably work well at the first impact locations, since the marker would still be vertical and basically undamaged.

Damage Analysis

Striations and damage on the bottom of the hull seemed to indicate that the boat ran over the I-Beam more than once. The boat may have struck the beam three or more separate times. After the initial collision, the boat went into circles and struck either the same I-Beam, or another hard metal object under water. Striations were found on the bottom of the boat that ran perpendicular to the centerline which had an arc shape that might be experienced if the boat were in a tight circle.

13.5.3.4 Summary

This collision was difficult because the examinations of the boat and the marker required more time than was available. Even given weeks to study and examine every detail, it would still have been difficult to determine the angle at which the boat was turning, if the boat was turning at all. A survey of the struck I-Beam would have told an interesting story and contributed valuable data to the reconstruction.

13.5.4 Accident No. 4:

13.5.4.1 Abstract

A 24 foot I/O cruiser with a small cuddy cabin shown in Figure 13-29 was reportedly traveling at high speed when it struck a barge. The cruiser was reportedly traveling on an angular course heading toward the front of the barge as shown in Figure 13-30. When the cruiser struck the barge, it suffered heavy bow damage. The barge was traveling forward at the time of impact. After impact, the cruiser disappeared from the view of the barge operator, and the boat was seen nearly completely submerged on the port side of the barge shortly after impact. The operator of the cruiser was the only occupant on board when the impact occurred. When rescue personnel got to the cruiser, the operator was not located. The body was recovered a day and a half later. Alcohol was a factor in the accident and the cause of death was ruled as drowning.

13.5.4.2 Critical Damage

Damage to the Cruiser:

An overall view of the damage done to the cruiser is shown in Figure 13-29. The primary damage was to the bow on both sides caused by direct contact with the barge. Figure 13-31 shows that the bow was damaged and had signs of crumpling on the surface; however, no deformations remained to indicate how far the fiberglass surfaces might have flexed. Striations as shown in Figure 13-32 were found on the starboard side and the bottom of the cruiser. Additional damage to the windshield frame and to the port

side of the boat was caused when removing the boat from the water. No striations were found on the bottom on the boat or on the barge which would indicate that this was an over-ride type of accident.

Damage to the Barge

Figure 13-33 shows an overall view of the barge that was struck. A single tug was pushing a total of fifteen barges. The tow was three barges across by five barges long. The cruiser struck the first row of barges as shown in Figure 13-30. Significant damage was visible on the front of the first and second barges from the left (facing forward). Most of the paint transfer was found in between the corners of the these two barges. No structural damage or significant deformations to the barge were noted, although minor damage to some equipment located on the front of the barge was reported.

13.5.4.3 Analysis

After an initial review of the damage done to both the cruiser and the barge, it was not obvious how the damage occurred. The goals of the analysis of this accident were primarily:

1. Determine the angle of impact.
2. Determine the sequence of events that resulted in the observed damage on both vessels.
3. Estimate the speed of the boat.

Navigation light analysis on the barge was not conducted since the barge was not available. Witnesses reported seeing that the barge lights and the cruiser lights were operating.

Several hypotheses were formulated to explain the damage patterns on the barge. Paint transfer was found at points A, B, C, D, and E. as shown in Figure 13-30. The heaviest paint transfer was on the corners of the two barges at points B and C. Some contact was also evident at points D and E. How did this damage occur?

Examination of the photos of the barge showed that the greatest impact and penetration probably occurred at points B and C. If this was true, then how did paint transfer get to points A, D, and E?

One early theory was that the boat initially struck the barge at point A, then slid along the leading edge of the barge until it reached the second barge at point B.

This hypothesis was formed to explain the paint transfer which was found at point A. This hypothesis was considered unlikely for several reasons. The direction of motion of a heavy motorboat traveling at high speed is not easily changed. The boat has a tremendous amount of inertia and momentum that will tend to carry

it in the same direction it has been traveling. Thus if the impact point had been at A, it is unlikely that the boat's velocity would have been significantly diverted into a direction parallel to the front of the barge, and then changed again to create the debris field shown in Figure 13-34. This hypothesis would be considered likely only if the impact angle were nearly parallel to the front of the barge and the debris field had been consistent with that direction of impact.

The diagrams in Figure 13-30 and 13-35 show what most likely occurred. The debris field which was photographed on the barge after the accident seemed to be focused sufficiently to indicate a direction of impact. When stronger emphasis was placed on the debris field, a more plausible theory came into consideration. Numerous fiberglass fragments, some several square inches in size, were found in a relatively straight line at varying distances from the impact point on the deck of one barge. This debris field was then assumed to be an indicator of the direction of impact. The analysis continued based on the premise that this was a correct assumption, and any explanation for the marks at points A must be consistent. It was realized that if the barge had penetrated deep enough into the bow of the boat, that the marks at point A on Figure 13-30 could have been possible. However, a survey of the damage to the outside of the cruiser did not indicate that the bow of the boat had been deflected to the degree necessary to account for this. Deflections of close to 12 inches or more in some portions might have been required. The key evidence was found when examining the inside of the boat.

Figure 13-36 shows the inside of the boat the way we found it after the accident. Some damage was noticeable, but nothing to indicate that the corners of the barge might have caved in the sides a distance of a foot or more. Fortunately, we had complete access to the boat, and destructive examination was permitted. After photographing and documenting the interior, and all apparent damage, we began to look deeper. All of the carpet, padding and loose furnishings were removed from the forward bow area. The goal was to get down to the bare inside of the hull. It was hoped that any wood in the structure would leave behind indicators of the degree of penetration. Figure 13-37 shows the forward area of the boat with the carpet removed. The fiberglass horizontal structure in the photo shows that it has been crushed, and failed in compression. The hull sides of the boat were literally pinched and compressed when the bow of the cruiser drove itself into the small gap between the two barges. Examination of the fiberglass on the inside showed obvious delaminations. The fiberglass layers on the inside had remained in a slightly compressed condition, and were from one to two inches away from the remaining outer layers. Wood in various parts of the bow structure showed fairly clearly how far the sides had been deflected.

After viewing the inside of the bow, and gaining a clearer understanding of the damage to the hull, the outside of the bow was again carefully examined. On each side of the bow, it was apparent just how far the barge had penetrated. The edge of penetration on the port side of the bow was further aft than on the

starboard side. This information was used to help construct the diagram in Figure 13-35. The diagram is drawn from the best information we had available at the time. No measurements were taken of the barge, nor was a ruler or other measuring device used in the barge photos. The diagram in Figure 13-35 is scaled based on the estimated width of a boot print made in the dust of the debris field on the barge! The cruiser is believed to have struck the barge and continued until the corners of the barge penetrated into the bow of the cruiser. Some ride up occurred, placing the cruiser at an increased nose up trim when it finally stopped. Since the barge was still moving forward, it may have thrust the stern underwater. It is also possible that the cruiser simply began to slip back into the water, and when it did the water entered through massive cracks in the bow. Either way, the boat began to sink. The striations on the side of the boat shown in Figure 13-32, and the damage done to the barge at point D in Figure 13-30 were probably caused when the barge began to run over the sinking cruiser.

Estimated speeds of the cruiser by witnesses were around 40 mph. Based solely on physical evidence, it appears likely that the cruiser was on plane, and traveling at least 20 mph. While the cruiser may have been traveling much faster, this one of those areas that it would difficult to prove a 40 mph velocity based on limited data available on boat structures. It must also be remembered that for all practical purposes, the fiberglass cruiser struck a solid steel object. Thus, it is possible to create serious damage without involving tremendous impact speeds.

13.5.4.4 Summary

This accident showed how truly resilient fiberglass can be. What appeared to be minor damage from the outside was really a hull which had been badly crushed, experiencing deflections as much as 12 inches or more. It was a lesson in the importance of getting all the way down to the bare hull on the inside when possible to examine the damage. Also of importance was the debris field photographed on the barge. The officer who investigated the accident is to be credited for having the foresight and thoroughness to have taken several photos of this evidence. It proved to the primary indicator which lead to a plausible reconstruction theory.

13.5.5 Accident No. 5:

Accident number five was a staged collision between a barge and a stationary motorboat. The motorboat was not available for analysis after the collision, so no analysis was performed.

13.5.6 Accident No. 6:

13.5.6.1 Abstract

Three men were on board a 19 foot outboard powered bass boat when it was struck by a 21 foot I/O cuddy cabin cruiser at night. The following summary is based on statements from the operator of the cruiser. The bass boat was first sighted while some distance away. It was ahead and off to the port side. The bass boat appeared to be on an opposite parallel course. The bass boat's lights then went off. The operator of the cruiser throttled back, and then saw the boat right in front of him. The cruiser turned hard to starboard, and struck the bow of the bass boat. The impact knocked a hole in the front of the cruiser, which quickly took on water and capsized. Four occupants were on board the cruiser, including one passenger who was trapped in the cuddy cabin while the boat was floating inverted. The passenger was pulled through the hole in the bottom of the hull to safety. The starboard side of the bass boat was badly damaged. All three men on board the bass boat were killed in the accident.

13.5.6.2 Critical Data

<u>Critical Data From the Target Boat (Bass Boat)</u>

An overall view of the bass boat is shown in Figure 13-38. A damage diagram for the bass boat is shown in Figure 13-39. The starboard side has sustained heavy damage. All of the damage was concentrated on the starboard side. There was no indication that the cruiser rode completely over the bass boat. The starboard side of the hull had been almost completely sheered off from the gunwale to the chine from the initial impact point forward all the way back to the operator's position, with one important exception. The section of the hull which contained the registration numbers was still largely intact. This piece is visible in Figure 13-38. This section was cracked along the chine, and had folded down into a horizontal position during impact. This section had not been sheered off like the hull sections on either side. An unusual set of striations as shown in Figure 13-40 was noted on the forward edge of this section of the hull. The striations are barely visible in the photo, but are actually two sets of marks. The first and most important is an "L" shaped set of continuous marks. The second set is a set of linear striations that are basically parallel to the vertical most portion of the "L".

The console and windshield at the operator's position was badly damaged. The windshield frame was knocked from it mountings.

The starboard side and forward edge of the console were removed during the impact. The steering wheel was bent slightly and the throttle lever had been broken off. The windshield frame was still entact, but had been struck by the hull of the other boat. The console showed signs that it been struck with a force aimed in the general direction of the aft port quarter of the

stern. The inboard side of the console had buckled under a compressive load.

Perhaps the most unusual damage was a set of cuts on the starboard side at the stern that appeared to be propeller cuts. These cuts are shown in Figure 13-41. The rub rail and gunwale in the area above the propeller cuts had been damaged. Something struck this area and pushed the rubrail and gunwale in an upward direction.

Additional striation marks were located on the forward portion of the starboard side on sections of fiberglass that were still attached to the lower edge of the cut out area. These marks were not linear, but contained a gentle curve.

Near the bow of the bass boat, a pedestal seat post remained inserted into its container in the floor of the boat. The post was constructed of a heavy steel, which was struck by the bullet boat. This post was approximately 59 inches from the tip of the bow. The post had a red decal near the top of the post which had been scraped and partially removed during the impact.

<u>Critical Data From the Bullet Boat (Cruiser)</u>

Figure 13-42 shows overall damage to the cruiser. Damage was concentrated on the bow, with striations along the port side. A damage diagram for this boat is shown in Figure 13-43.

The damage to the bow is shown in Figure 13-44. A large hole in the bow of the boat, measuring approximately 11 inches by 22 inches across is evident. Also evident is a tear that extends from the hole toward the stern off the starboard side at point A in Figure 13-43. The hole was enlarged to pull the occupant from the cabin after the boat capsized.

Numerous striations along the port side of the hull are shown in the damage diagram in Figure 13-43. Among the most interesting were a set of marks shown at point B on the diagram. These marks form a gently curving "S" shape.

Another unique set of marks appear on the port side at point C. These marks appear on the vertical face of the second chine underneath the boat. The inset at point C on the diagram in Figure 13-43 shows the approximate shape of these marks when viewed from the side.

Perhaps the most critical evidence were the marks located on the propeller of the bullet boat. Two blades clearly had gelcoat on the blade tips which matched the colors of the bass boat where the cuts were located.

Some damage was done to the windshield frame where occupants had impacted it during the collision. The engine cover was damaged but it appeared to be more related to the capsizing than the collision.

13.5.6.3 Analysis

This accident was unusual, fascinating, and difficult to reconstruct. It is worthwhile to look closely at many of the details and the thought process that went into this reconstruction.

Both boats were examined to look for any signs of a complete over-ride. We wanted to determine if the cruiser entered on the starboard side, slid across, and re-entered the water on the opposite side. There was no damage to either the opposite stern or the opposite side of the boat to indicate that any contact was made. This was not proof that an over-ride had not occurred, since often the far side of the boat will be cleared completely. The aft end of the cruiser's bottom was examined and striations were found near the stern on the port side. Thus, initially we could not conclude that an over-ride may not have occurred.

This was one of those accidents where it was not at all obvious what had happened. Eventually the pieces began to fall into place. The propeller marks on the starboard side near the stern of the bass boat positively located the stern of the cruiser at some point during the collision. Matching gelcoat on the propeller blade tips confirmed that these were indeed propeller cuts.

The initial impact point appeared to be the leading edge of the damaged area on the bass boat near the bow on the starboard side. The pole for the forward seat appeared to have been responsible for the long gash in the hull of the cruiser. A small fragment of red decal mounted on the pole was found inside the cuddy cabin of the cruiser near the gash. Since there was nothing red in the colors of either boat except the decal, this proved to be a good indicator that the pole had penetrated the cruiser in the forward area.

The cruiser struck the bass boat in an area near the bow that was heavily reinforced. The size and shape of the hole in the cruiser suggests that it was fairly close to a direct impact on that portion of the bow. In other words, the centerline of the cruiser was close to perpendicular to the perimeter of the hull at the initial impact point. This would help to explain why the collision resulted in a hole in the cruiser rather than resulting in an over-ride. If the bass boat made an evasive turn to port, as the operator of the cruiser stated, then the roll angle of the bass boat would place the edge of the hull at an angle closer to 90 degrees to the rake of the bow. This would even further encourage the hole in the cruiser.

The angle of the gash made by the pole as shown in Figure 13-43 is one indication that the bass boat was moving at the time of the accident.

So far we have enough information to conclude that the cruiser struck the bass boat on the starboard bow. The initial impact angle was somewhere between a right angle and something closer to

a head-on impact. The bow of the cruiser penetrated through the bass boat until it reached the post, which caused a diagonal gash in the hull of the cruiser. The hard part was to determine what happened next.

One possible scenario was that the cruiser struck the bass boat nearly head on, and then veered off to port. Next the cruiser could have slid down the side of the bass boat with its starboard side in contact nearly the entire time. This could have accounted for the propeller cuts in the hull on the bass boat, but there were still too many questions unanswered by this proposal. For one, there were no marks on the starboard side of the cruiser's hull bottom, aft of the gashed area in the bow. There were also extensive marks on the port side of the hull bottom, which would have never have come in contact with the bass boat if the above were true. While it is possible that some of the hull markings could have been unrelated to the accident, this was not considered likely at the time. Now what?

Several key questions had not yet been answered. Careful analysis of the remaining data was needed. For the damage to be consistent, we needed a scenario which placed the port side of the cruiser in contact with the bass boat, placed the propeller in contact with the hull side at the stern, and maneuvered the pole in the front of the bass boat to match the gash in the bow of the cruiser. The scenario shown in Figure 13-45 was formulated. Was there any additional evidence to support or contradict this hypothesis? The answer was yes!

The hull section shown in Figure 13-38, which had remained attached to the chine, was unusual for two reasons. First, because it was still there when hull material on both sides was gone, and second because of the marks shown in Figure 13-40 on the forward edge of the hull section. The "L" shaped marks were likely made while the boat was rotating and pivoting part way through the collision. This hull section was probably parallel with the floor of the bass boat during this rotation. The tightness of the "L" of the marks suggest that the relative linear velocity of the two boats at the point where these marks were made was virtually zero. The mark appears primarily because of the relative angular velocity of the two boats.

The tightness of the "L" also offers an explanation as to why this section of the hull was still attached. If the two boats had been sliding across each other at a high rate of speed, the effect may have been to shear this section off along with the rest of the hull material. The near zero relative velocity between the two vessels at this point would have made it easier for this section to remain in place.

The damage to the operator's console and windshield frame was also consistent with the pivoting hypothesis. The console was probably struck fairly hard and served as a pivot point which kept the cruiser from ending up completely on top of the bass boat during the pivoting action. This was probably what caused the inside supporting wall of the console to buckle as described

earlier. The windshield frame had been struck by the hull of the cruiser. Damage found at point C on Figure 13-43 suggest that the windshield frame might have made an imprint on the second chine on the vertical portion on the cruiser's hull, though this was not confirmed.

While it is difficult to explain in words alone, the "S" striations located at point B in Figure 13-43 made sense when examined in light of the pivoting hypothesis. If one takes the damage diagrams and maneuvers the boats through the sequence, it becomes more apparent how these marks might have been created as the boat pivots.

The last issue was to resolve the propeller cuts and the damage at the stern around the rub rail. Even if the bass boat had pivoted while underneath the cruiser, that still did not explain how the propeller of a boat nearly eight feet wide at the transom made contact with the hull of the bass boat. Figure 13-46 gives us a possible answer. This figure is a scale diagram of half of the stern of both boats. The bass boat is on the bottom, and the cruiser is on top. This diagram shows the approximate orientation required for the propeller of the cruiser to make the propeller cuts in the bass boat. This diagram is only an approximation since the outdrive is shown in a straight ahead position. Remember that the cruiser was possibly in a turn to starboard and that this would have affected the location of the propeller as it is shown in the figure. If the cruiser had been in a hard turn to starboard, the engine thrust would have helped to contribute toward the pivoting of the cruiser. A hard turn to port for the bass boat would also have contributed to the likelihood of this scenario.

Estimated Speeds

A striation analysis similar to that performed on the first few accidents was not appropriate here. For one, we know that the relative velocities of the two boats changed significantly during the impact, making such an analysis difficult. What was the speed of the two boats? While it is not possible to say for certain, several things seem likely.

Obviously the bullet boat was moving. It is also probable that the target boat was moving. The operator of the bullet boat claimed that he was on plane. The initial damage to the bow of the cruiser made by the pole on the bass boat is somewhat analogous to the striations used in earlier analysis. If the two boats struck at roughly a right angle to each other, the angle of this cut suggests that both boats were traveling about the same speed at impact. We must be careful here because the orientation and speed of both boats may have changed significantly before the pole cut the gash in the hull.

It is also likely that what actually occurred is that the bass boat pivoted underneath the cruiser, although the heading of the cruiser was probably altered slightly. This is primarily because the cruiser is much more massive than the bass boat. In order for

the bass boat to pivot as it did, most likely it was on plane. While it has not been proven by testing, the theory exists that a boat on plane may rotate much more easily than the same boat sitting still or traveling at displacement speeds. This is largely due to the fact that only the rear third or less of a boat may be in contact with the water at planing speeds. For a boat on plane to rotate easily during an impact, this theory also assumes that the impact force is well forward and imparts a high moment about the boat's CR.

13.5.6.4 Summary

It appears likely that both boats were at least on plane and that the initial impact angle was as shown in Figure 13-45. The sequence of events shown in Figure 13-45 is the best hypothesis to account for the physical evidence on both boats. While it was not discussed in this analysis, this hypothesis was also consistent with what little was known about the occupant dynamics during the collision.

It should be noted that the reconstruction of this accident would not have been possible except for the fine work done by the investigating officers. They took photographs of both boats at the scene which proved valuable in the reconstruction. Photos taken of the cruiser while it was still capsized in the water helped to show that damage in some areas on the hull bottom was not done while the boat was being retrieved from the water. The officers also protected both boats until all necessary data was obtained. Lastly, their accident report contained unusually thorough and accurate diagrams of the damage done to both boats.

13.5.7 Accident No. 7:

13.5.7.1 Abstract

A 20 foot I/O open motor boat struck a stationary 21 foot long cuddy cabin cruiser. The boats are shown in Figures 13-47 and 13-48 respectively. The impacting boat struck the cruiser from nearly dead astern and rode completely over the cruiser. Fortunately, no fatalities occurred as a result of this accident.

13.5.7.2 Critical Data

Critical Data From the Target Boat:

The struck boat was struck on the starboard side of the transom. This area is shown in Figure 13-49. The windshield frame on the starboard side of the boat had been severely damaged. The instrument console suffered from an impact either by the bow of the

boat or the skeg. The windshield frame that ran along the side of the boat, parallel to the centerline, had a single cut in it, transverse to the centerline of the boat. Figures 13-50 and 13-51 are sketches of the damage done to the target boat.

Critical Data From the Bullet Boat:

The bullet boat showed striations along the bow and along the bottom of the hull. There was no severe visible damage done to the hull of the bullet boat. The glass in the side windshield on the starboard side was broken and the frame was warped. One propeller blade had a chip in it. The port chine of the boat, nearly two-thirds of the way back from the bow, had experienced severe scrapes. The scrapes were consistent with damage that occurs when fiberglass rubs along aluminum.

13.5.7.3 Analysis

This accident was fairly straight forward so a detailed analysis will not be presented here. The damage to the transom of the target boat was clearly the point where the motor boat entered the cruiser. The damage to the target boat indicated that the bullet boat had sufficient speed to almost jump completely over it, at least enough to nearly clear the instrument panel. No definite contact marks could be found to prove that contact was made beyond the windshield. Apparently, the bullet boat was airborne, and cleared the starboard side of the bow.

The bow of the bullet boat struck and slid across the vinyl on the top of the instrument panel. The impacted area was about two inches wide and not very deep. This helped to rule out the skeg as the striking object. Some of the instruments and small pieces of debris were sent flying through the instrument console and into the cuddy cabin interior, presenting a risk of injury to the occupants in the cabin.

Witnesses stated that the cruiser was stationary at the time of impact. Striations on the bottom of the bullet boat hull were parallel to the centerline of that boat. Since the velocity of the bullet boat was parallel to the centerline of the target boat, it was not possible to tell if the target was moving at impact.

Determination of the impact angle and the direction of impact were fairly simple. The bullet boat struck the target boat in the transom, approximately two feet to starboard of the centerline. The centerline of the target boat was at approximately a 10 degree angle to the velocity vector of the bullet boat. Conventions used in previous examples allowed us to state the impact angle based on the velocity vector of the target boat. Since the velocity of the target boat was zero, we must refer to the direction of the centerline of the target vessel instead.

Estimating the Bullet Boat's Speed

This accident provides an opportunity to discuss possible methods of analyzing and estimating boat speeds. The bullet boat marked a fairly clear path across the target boat. Absence of any contact damage beyond the windshield and dash area show that the bullet boat became airborne. Several possible methods could be used to estimate the bullet boat's speed. The possible methods are briefly summarized below:

Method 1: Use the conservation of energy approach. Estimate the absolute minimum change in height of the CG, and apply the formula:

$$V = \sqrt{2gh}$$

This method calculates the most conservative speed possible for a given change in CG height. The geometry of the each boat will suggest a minimum CG height. The difficulty with this method is attempting to account for the amount which the target boat would have been depressed due to the weight and dynamic loads of the bullet boat. One possibility for dealing with this variable is to neglect the depression when a large boat is struck, and treat the calculation as an estimate, not as a minimum speed.

Method 2: The second method involves using the trajectory equations discussed in Chapter 11. The difficult part of the analysis is determining the minimum trajectory you wish to analyze. There are two basic approaches to establishing this information.

Both methods involve determining the area below which the CG could not have fallen during the collision. Figure 13-52a shows how this area was determined for accident number seven. We will refer to this area as the non-penetration zone (NPZ). Parts of the bullet boat will have clearly penetrated the NPZ, but not the CG. Figure 13-52b illustrates a possible NPZ for accident number seven. Obviously, the determination of this area is subjective and depends at least partly upon how much the target boat was depressed during the impact. Note that it is not necessary to know the vertical height of the CG within the bullet boat, since we are only interested in the change in the CG height and not the absolute height.

Method 2A: Now that we have established a NPZ, how do we analyze it? One method is to presume that the launch point of the CG is at or near the impact point, and assume that the rest of the motion can be analyzed as a trajectory motion problem. In certain accidents, this is clearly a reasonable approach when it is known that the bullet boat was essentially launched over the target boat. The appropriate trajectory formulas are selected based on the shape of the NPZ, and provide an estimate of the bullet boat's speed. Figure 13-52c illustrates this method.

Method 2B: A second method for analyzing the NPZ is used when it is presumed that the bullet boat slid across the target boat instead of jumping over it. Use of the trajectory formulas in these accidents can create estimates in excess of the actual speed. The first approximation that should be used in a sliding accident is the conservation of energy method previously outlined in method one. The problem with this method is that it is generally thought to be overly conservative. In certain scenarios, when little or no physical damage is involved, and the coefficients of friction are low, this method may provide a reasonable first approximation.

Method 3: This method for analyzing collision over-rides assumes that the first part of the collision involved sliding, and the second part of the impact involved an airborne trajectory. Virtually all collision over-rides can be broken down into a contact or sliding phase and an airborne phase.

The analysis of the sliding phase is similar to estimating speed from skidmarks for an automobile on a sloping roadway. The missing ingredient at this time is, of course, the coefficient of friction. Hopefully, future testing and research will provide reasonable estimates of the friction coefficient for two boats in contact.

The airborne part of the collision can be analyzed using the trajectory equations. The analysis is now similar to that described in method 2B, except that the starting point for the trajectory is not the impact point, but the location of the CG when the two boats were last contacting each other.

Which method to use for the analysis depends largely upon the determination of how much of the impact was sliding and how much involved an airborne trajectory. If only light damage or contact occurred after the initial impact point, it may still be acceptable to use the trajectory equations as described in Method 2A. Accident number seven is a good example of this situation. The contact damage which occurred after the initial impact point was relatively slight.

An analysis was conducted to provide speed estimates based on the diagrams in Figure 13-50. The figure number, equation, and the results are presented in the summary that follows.

Figure 13-52b:

$$V = \sqrt{2gh}$$

where h is equal to the change in height of the CG, which is approximately four feet. The height at point A was 1 feet, and the height at point C is five feet.

$$V = \sqrt{2(32/2)(4)} = 16\ ft/sec\ (11\ mph)$$

Figure 13-52c:

Use equation 11-6. Assume that point B is the launch point. Calculate the minimum speed required to clear point C and then for point A. Use the higher of the two speeds as an estimate.

Equation 11-6:

$$V = \sqrt{g(e+\sqrt{D^2 + e^2}}$$

For point C: $e = +3$ feet, $D = 10$ feet

$V = 20.8$ ft/sec

For point D: $e = -1$ feet, $D = 23$ feet

$V = 26.6$ ft/sec (18.1 mph)

Note how the maximum distance used for D was determined. The bullet boat struck the target boat at an angle and cleared the starboard side just short of the bow. The distance D assumed that the bullet boat cleared the target boat just short of the bow. If the direction of the bullet boat had been such that it cleared the bow, the maximum distance D would have been equal to the length of the target boat plus the distance of the CG from the stern of the bullet boat. For this analysis, we assumed that the CG of the bullet boat was 1/3 of the distance forward, or approximately 6.7 feet from the stern.

Figure 13-52d:

Use equation 11-6 again, but assume that the launch point is at point C. Calculate the minimum speed required to reach point D.

$e = -4$ ft, $D = 13$ ft

$V = 17.6$ ft/sec (12 mph)

This velocity is the minimum velocity required to launch the boat from point C so that it reaches point D. Note that the boat needed a velocity greater than 17.6 ft/sec at impact for this to be possible. How fast was the boat traveling at impact to still be traveling at 17.6 ft/sec when it reaches point C?

The conservation of energy principles will again let us estimate the minimum impact speed if the boat still had a velocity of 17.6 ft/sec at point C. In order to provide the minimum estimate of the impact speed, we will assume that no energy was lost. The sum of kinetic and potential energy at one point must be equal to the sum of the kinetic and potential energy at the second point, as shown in the following equation:

$$KE1 + PE = KE2 + PE2$$

Remember that $KE = 1/2(m)V^2$, and $PE = mgh$. Substitute, divide through by m, and we get the following:

$$.5V1^2 + gh1 = .5V2^2 + gh$$

V2 = 17.6 ft/sec
h1 = 0
h2 = 4 ft
g = 32.2 ft/sec^2

Substitute the above values, and solve for V1:

$$.5V1^2 = .5(17.6)^2 + 32.2(4)$$

$$.5V1^2 = .5(17.6)^2 + 32.2(4)$$

$$V1 = 23.8 \text{ ft/sec} \quad (16.2 \text{ mph})$$

Based on these calculations, the minimum speed at impact would have been 23.8 ft/sec.

Even though we do not have measured values for the coefficient of friction for the two boats in contact, the following example shows how this information might be used when it becomes available.

The analysis is limited only to the sliding phase of the collision as labeled in Figure 13-52d. The derivation and background for this analysis can be found in Traffic Accident Reconstruction, Volume 2, Topic 862, Section 7. Consult the bibliography for complete information.

The following equation can be used to estimate the initial velocity required when an object, boat or otherwise, slides for a distance d, and decelerates or accelerates at rate a.

$$Vi = \sqrt{Ve^2 - 2ad}$$

where Vi = initial velocity
Ve = final velocity
a = acceleration (minus values indicates deceleration)

d = the distance the object slides

In this accident, we will view the first portion of the accident as a boat sliding up a ramp. We want to find the initial velocity required to slide the boat up the ramp so that it still has a velocity of 17.6 ft/sec at point C, which is the top of the ramp. Let us first make a few assumptions. For the sake of discussion, we will assume that the dynamic coefficient of friction for the two surfaces on a level plane is 0.2. This is also equivalent to the drag factor. The acceleration or deceleration can be related to drag factor by:

$a = fg$, where f is the drag factor.

The distance that the boat slid is somewhat subjective. For sake of illustration, we will use the hypotenuse of a right triangle with a base of 10, and an altitude of 3. For this case,

$d = 10.44$ ft

If this were an accident on a level surface, we would have everything we need to estimate the initial velocity. We need to take into account the slope of the ramp. The drag factor for a grade is given by the formula:

$$f_g = (u + G) / \sqrt{1 + G^2}$$

where u = coefficient of friction (which is also the drag factor in boat collisions for a level surface)

G = grade expressed as a decimal

The grade for this problem is:

$G = 3$ ft/10 ft $= 0.3$

The drag factor for the slope is:

$$f_g = (0.2 + 0.3) / \sqrt{1 + 0.3^2}$$

$$f_g = 0.48$$

From a = fg, calculate the new value of a for the slope:

$$a = -0.48(32.2)$$

$$a = -15.4 \text{ ft/sec}^2$$

The value of the acceleration is a minus since the boat is slowing down.

Substitute all values obtained into the Velocity equation and solve for Vi:

$$Vi = \sqrt{Ve^2 - 2ad}$$

$$Vi = \sqrt{17.6^2 - 2(-15.4)(10.44)}$$

Vi = 25.12 ft/sec (17.1 mph)

It is important to note that the last analysis makes many assumptions. The coefficient of friction of 0.2 for two fiberglass boats is merely an educated guess. No testing has been conducted to generate this data. The analysis does provide insight into how the drag factors can be measured. These values could be obtained if the initial and final velocities can be carefully monitored over a given distance in a test collision. Of course, this would not directly account for the energy losses due to structural damage which may occur.

The above method needs additional refinement. The actual distance (d) to be used in these equations is open to discussion. This analysis did not consider what is labeled as the "pre-ramp area" in Figure 13-52d.

13.5.7.4 Summary

The analysis of this accident showed several possible methods for estimating speeds in an over-ride type accident. The methods presented provide speed estimates ranging from 11 mph to 18.1 mph. Clearly, the 11 mph estimate is overly conservative. The higher

estimate of 18 mph is probably closer to the actual speed. For the forseeable future, methods for estimating speed in over-ride accidents will probably be based on collision geometry, trajectories, and possibly friction data. Until it becomes possible to relate structural damage to energy, the best estimates for speed in an over-ride type accident will probably be based on these parameters.

The methods presented assumed that the target boat was stationary. If the target had been moving, an analysis is still possible, but the speed of the target must be included in the analysis. The automobile accident reconstruction community has developed formulas for dealing specifically with same direction automobile impacts. These formulas can be adapted to apply to the situation in Accident No 7 for scenarios where the target boat has attained a significant velocity. Consult the Traffic Accident Investigation Manual, Volume 2 listed in the Bibliography for more information.

It is important to note that all of the methods presented in this collision analysis were oriented toward establishing a minimum theoretical speed instead of an estimate of actual speed. Each method presented requires data that is subjective and difficult to precisely determine. Caution is encouraged in using these methods since errors in the input parameters could conceivably produce speed estimates that are beyond the actual speed.

13.5.8 Accident No. 8:

13.5.8.1 Abstract

A 19 foot I/O traveling at idle speed was struck from the stern by a second vessel at night. The second vessel, in this case the bullet boat, struck the stern, and rode over a portion of the struck boat. The second vessel was released almost immediately after the accident; and therefore, was not available to us for analysis. An overall view of the target boat is shown in Figure 13-53. There were no fatalities in this accident.

13.5.8.2 Critical Data on the Target Boat

Damage to the rear of the boat is shown in Figure 13-54. The damage on the port side of the transom appears to be the point where the lower unit of the bullet boat passed through. If the target boat was traveling very slowly, then this would also be the area where the bow made initial contact. A handrail was crushed on the starboard side of the stern. The side windshield frame on the port side had been lightly struck, showing striations, and slight deformation outward.

13.5.8.3 Analysis

Unfortunately, without analyzing the bullet boat, a positive reconstruction was not possible. All damage surveyed indicated that the bullet boat struck the port stern, and rode over the port quarter of the target boat. Examination of the bottom of the hull on the bullet boat would have likely confirmed the relative speed of the two boats.

13.5.8.4 Summary

This collision provided one example of how important it is to have access to both boats involved an accident if a reconstruction needs to be performed.

13.5.9 Accident No. 9:

13.5.9.1 Abstract

A 20 foot I/O open motorboat struck a 20 foot pontoon boat powered by a 40 HP outboard motor. The motorboat struck the pontoon boat on the port quarter and rode over the boat, exiting the starboard side near the stern. The pontoon boat carried nine passengers. Two were killed, and three were injured. Three occupants were on board the motorboat, one of which suffered minor injuries. The occupants on board the motorboat said that the jolt was fairly minor, as if they had run over a log. The port pontoon was punctured by the motorboat, and quickly filled with water. The pontoon boat then quickly capsized. An overall view of the pontoon boat and the motorboat are shown in Figures 13-55 and 13-56 respectively. The primary questions in this accident were as follows:

a. What was the speed of each boat?
b. Were the navigation lights on the pontoon boat running?

The analysis presented in this section will answer the question of speed to the extent possible based on the available data. The investigating officers attempted to answer the second question based on witness statements since the stern light was knocked from the pontoon boat and not recovered.

This accident was important because of the types of damage left behind. Clear examples of damage matching were identified to help determine the relative positions of the two boats as the impact progressed. The focus of the report on this accident will be to highlight these examples.

13.5.9.2 Critical Data

Damage Used to Determine Relative Positions

For this accident, we will deviate from the format of the previous accident discussions. This accident provided excellent examples of how damage matching can be used to determine relative locations of the boats. We will discuss the most important ones.

Figure 13-57 and 13-58 show the damage to the port quarter of the pontoon boat. Damage to the pontoon caused by the outdrive and propeller is clearly visible on the port pontoon. This is probably the most obvious example of damage matching. The propeller of the boat clearly caused this damage.

The portable fuel container on the starboard side was knocked off during the collision, but was set back in its place for the photo. Figure 13-59 shows a dent in the corner of the gas can. In order to identify what may have caused the dent in the gas can, it was necessary to get a clearer picture of the shape of the dent. A large slab of "Silly Putty" was worked into the dent and then carefully removed. When removed, the putty resembled the approximate shape of the object which struck the gas can. The shape of the putty resembled that of the torpedo, or the gearcase on the outdrive of a boat. The torpedo on the bullet boat was examined, and small traces of red paint were noted on the starboard leading edge of the torpedo. Figure 13-60 shows that the dent in the gas can matched perfectly with the leading edge of the starboard half of the torpedo.

The leading edge of the torpedo contained a hole approximately one inch across as shown in Figure 13-61. The hole was not in the exact same location which struck the gas can, nor is it likely that the impact with the gas can could have caused this damage. The hole was not circular, it contained precise definition and was an unusual shape. Once again, the putty was placed in the hole, and removed to get a better idea of the shape of the object which caused the damage. It had to be something strong, solid, and hard to create the hole in the thick leading edge of the torpedo. Figure 13-62 shows the steel brackets which were used to form the mounting brackets for the outboard motor. The torpedo of the bullet boat is believed to have struck the corner of the steel bracket. The bracket had obviously been struck, and the tip of it was left clean and shiny by the impact.

Aluminum railings went around the perimeter of the pontoon boat. All of the railings in the impacted area had been swept from the boat by the impact. The officers at the scene of the accident were thorough and retrieved loose wreckage and floating debris. They also retrieved railing parts. Figures 13-63 and 13-64 show where the bow hook of the bullet boat first struck a piece of the aluminum railing. Study of pre-accident photos provided by the owners helped to position this piece of aluminum at its proper location.

Seats covered with a brown vinyl material were used on board the pontoon boat. Brown streaks were noticeable in several locations on the bullet boat. One interesting set of marks is shown in Figure 13-65. The marks correspond precisely to the edge of the seat located near the point of impact. Apparently, the seat was struck, and thrown clear of the hull since striations do not accompany these marks. This is a good example of an imprint.

13.5.9.3 Analysis

This information was plotted on a damage diagram and the approximate impact angle was estimated to be 75 degrees. Figure 13-66 shows the path of the outdrive as indicated by the measuring tape placed across the stern. Sufficient data was not available to conduct a meaningful striation analysis.

13.5.9.4 Summary

This accident provided numerous examples of damage that showed conclusively the path which the bullet boat took across the target boat. Photos of the boat which were taken prior to the accident were valuable because they showed the positions of the seats, railings and other items struck by the bullet boat. Since there was little change in bullet boat's CG height, a trajectory analysis probably would not provide a meaningful estimate of the speeds involved. One possible method for obtaining a speed estimate for this accident may be to analyze the bent steel used in the frame for the motor mounts. Another possibility is that a highly detailed mapping of the path of bullet boat across the target boat could be used to obtain a relative direction of motion, which should produce a credible velocity ratio. The speed of the two boats can then be approximated based on witness statements for the speed of either craft. If the target boat was stationary however, this approach will not provide any useful data since the velocity ratio would be zero.

13.5.10 Accident No. 10:

13.5.10.1 Abstract

Two boats collided during a rain storm in the middle of the day. Both boats were approximately 19 feet long. The bullet boat smashed into the port side near the bow of the target boat. The bullet boat sank and was not recovered at the time of our analysis. Thus, we had only the target boat to examine. Witness statements placed both boats' speed at about 25 mph prior to impact. This accident was unusual in that it was a pure penetration collision. The bullet boat penetrated the side of the target boat without an

over-ride occurring. The bullet boat penetrated some distance into the target boat. The damage shown in Figure 13-67 was caused when an occupant of the target boat was thrown through the windshield. Figure 13-68 shows the damage to the hull of the target boat. There were no fatalities in this accident.

13.5.10.2 Critical Data

This accident was a challenge from the standpoint of only having one boat to examine. Many answers went to the bottom with the bullet boat. Nonetheless, several items are worthy of comment.

The bow light from the bullet boat was found just forward of the operator's seat on the target boat. This was significant because it helped to establish that the bow of the bullet boat definitely penetrated the hull of the target boat.

The general shape of the damaged area is significant. The forward most area of the cut out area is believed to be the initial impact point. The navigation light from the bullet boat appears to have penetrated through the forward area of the cut as shown in Figure 13-69. The navigation light from the bullet boat was found in the target boat in front of the operator's seat. The bow of the bullet boat actually cut through the hull, but the side of the navigation light housing may have cut the notch shown in this Figure. If this is true, it may also show the approximate angle of the two boats at impact. The navigation light impact point is fairly low on the hull of the target boat. If the other boat was on plane, then the initial impact area of the target boat must have been raised higher than normal. Either the target boat was plowing, or engaged in a hard turn to starboard. Witness statements indicated that both boats were on plane at impact. Figure 13-69 indicates that the bullet boat may have been in a turn to starboard at impact.

13.5.10.3 Analysis

The general shape of the damaged area suggest that the target boat was moving. The bow of the bullet boat began to penetrate, and made a sweep through the side of the hull. If physical data were known on the shape of the bullet boat, it may be possible to obtain enough information from the shape of the cut to determine the relative speed and impact angle of both boats. For example, the cut in the side begins at only a few inches high and grows until it stretches from the chine to the rubrail. The last part of the cut most likely matches the cross section of some part of the bow of the bullet boat at the angle of penetration at the accident. The rate of growth in height of the penetrated area, combined with the rake of the bow of the bullet boat, suggest a rate of penetration and relative impact angle. The diagrams shown in Figures 13-70 and 13-71 are rough sketches drawn to scale while

examining the boat. These diagrams should be sufficient to reconstruct a scale model of the target boat. If the bullet boat could be retrieved, a scale model of it could be constructed as well. The two models could then be manipulated until the penetrating hull of the bullet boat matched the damage in the side of the target boat.

Red paint striations too light to show up in a photo were found along the rub rail approximately three feet back from the bow, almost directly over the initial penetration point. A soft rubbery substance was found on the aluminum edge of the rub rail on the target boat in the same location. This was likely transfer of the rub rail material from the bullet boat.

13.5.10.4 Summary

The most likely scenario appears to be that the bullet boat was in a turn to starboard at impact. The target boat was most likely in a turn to starboard also. The boats hit traveling toward each other, with an approximate impact angle from 225 to 270 degrees as shown in Figure 13-72.

Unfortunately, the above is an unconfirmed hypothesis that might explain the damage to the target boat. Further reconstruction of this accident would require some knowledge of the shape and size of the bullet boat, and ideally the bullet boat itself.

13.6 General Notes on Interviewing Witnesses

The purpose of our investigations was to reconstruct the accident to the extent possible based solely on physical evidence. Thus, we did not interview witnesses, but did review the witness statements taken by investigating officers when they were available. Many times witnesses were asked to comment about speed of either their boat or the other boat, and to make estimates regarding distances.

Judging speed and distance on the water is tricky business, especially at night. More reliable and accurate answers regarding speed might be obtained by simply trying to ascertain the rough attitude of the boat. That is, was the boat on plane, below planing speed, or plowing? Most witnesses, especially occupants of the boat, should be able to provide those answers fairly accurately.

No magic formulas exist for judging distance. Just keep in mind that speed and distance estimates provided by witnesses, regardless of their location, can be very subjective and are prone to contain inaccuracies.

13.7 Conclusions

The techniques for accident reconstruction presented in this report came about largely because of the experience gained during the field accident case studies. The techniques of striation analysis provide valuable tools in analyzing over-ride accidents.

This analysis can identify the initial impact angle, the velocity ratio, and can lead to speed estimates for one or both boats. The striation analysis is especially useful when a trajectory analysis is not possible or provides overly conservative results.

A trajectory analysis can be expanded and applied to over-ride accidents where a significant change in the CG height of the bullet boat can be documented. The examples provided in the analysis of Accident No 7 assumed that the target boat was stationary. Between the trajectory analysis, the combination trajectory/friction analysis, and the striation analysis, we now have reconstruction tools for over-ride accidents where the target boat is stationary, and where both boats are moving.

Collisions with a Fixed Object (CWFXO) will remain one of the most difficult types of accidents to analyze. Estimating speeds and decelerations is not an easy task. Possible analysis methods have been presented in the Marine Accident Investigation Workbook used in seminars taught by UL on Boating Accident Investigation. If an initial speed is known, the average deceleration experienced can be estimated if the deceleration distance is known. Using the same concept, if the deceleration rate were somehow known, the initial velocity could be estimated. Speed estimates can possibly be based on needle slap, yet so far it has not been proven that needle slap occurs with any degree of consistency in boat accidents.

Figure 13-1

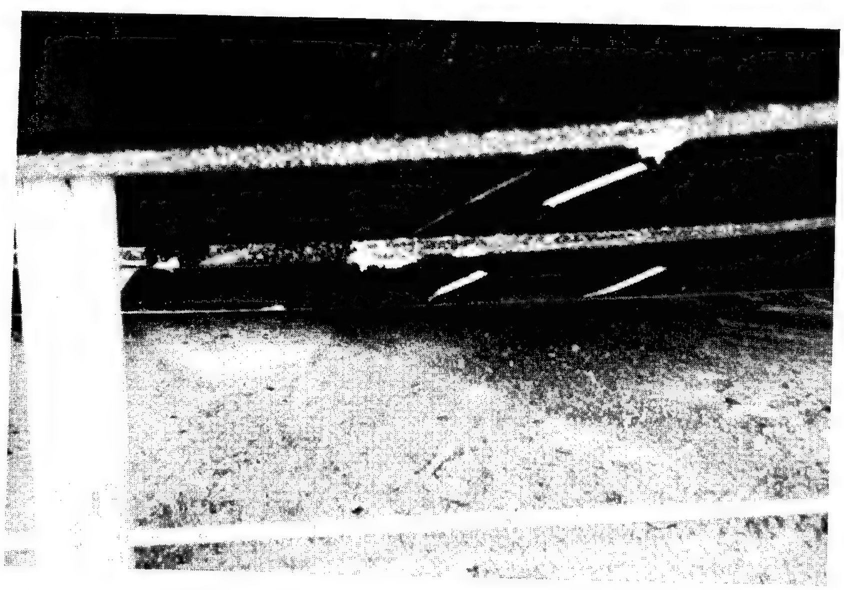
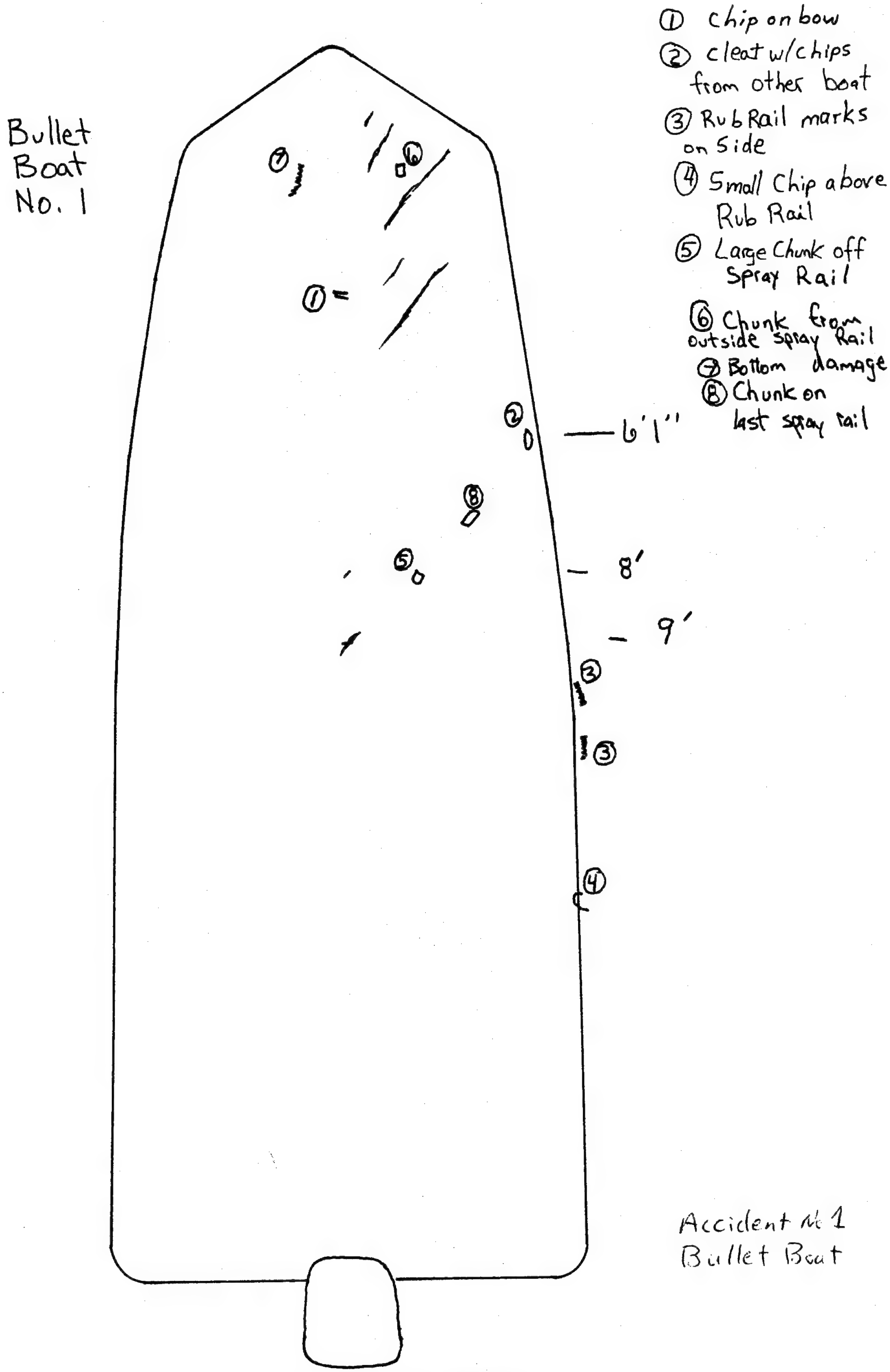


Figure 13-2



Bullet Boat Damage Diagram
Figure 13-3

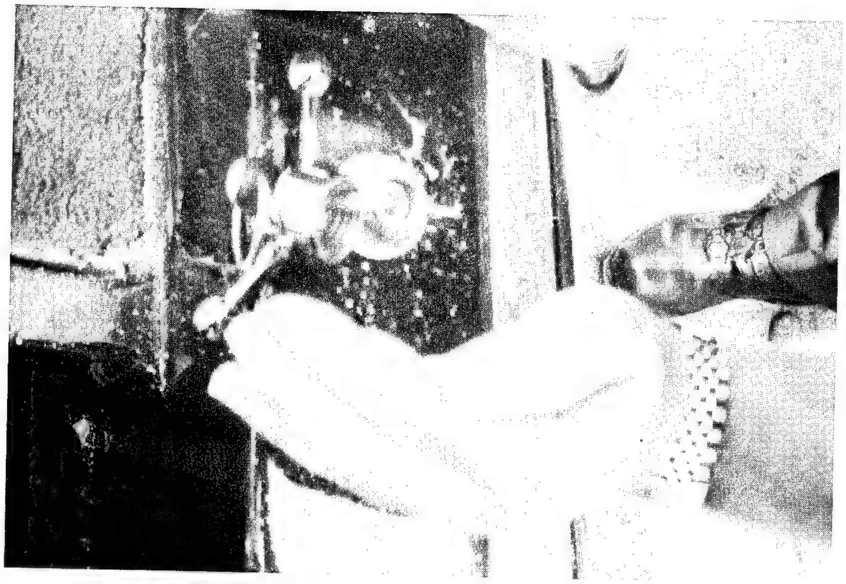


Figure 13-4

Figure 13-5

Figure 13-6

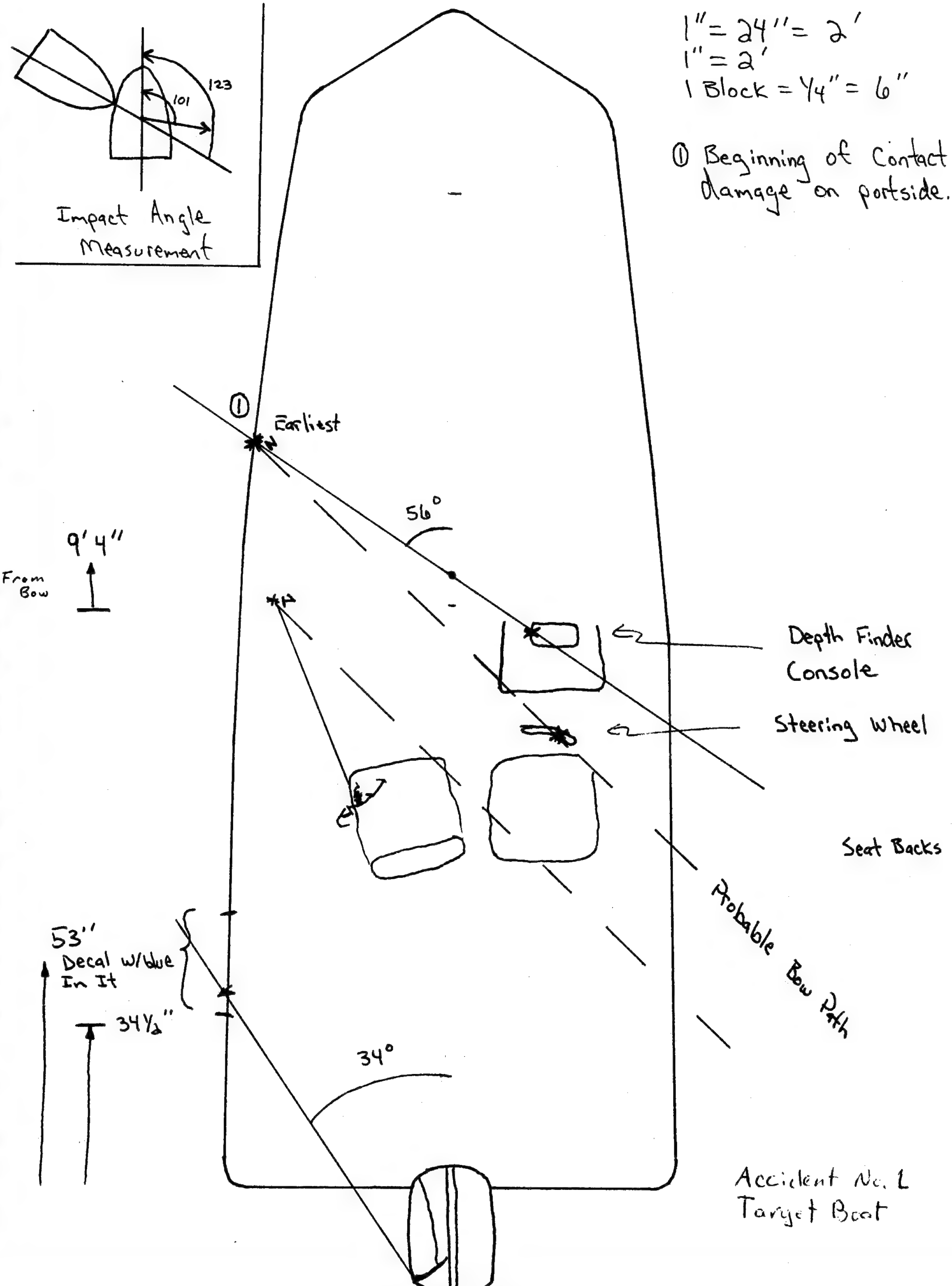

1" = 24" = 2'
1" = 2'
1 Block = 1/4" = 6"
① Beginning of Contact damage on portside.
Impact Angle Measurement
123
101
① Earliest
56°
9' 4"
From Bow
Depth Finder Console
Steering Wheel
Seat Backs
Probable Bow Path
53"
Decal w/blue In It
34 1/2"
34°
Accident No. 1 Target Boat

Figure 13-7

Accident No:1, Striation Analysis for θ2 = 101 degrees.

The following shows how the ratio of V2/V1 varies when θ2 := 0 deg, and θ3 is allowed to vary from 130 deg to 150 deg.

$i := 130 \,..150$

$\theta2 := 101$

$\theta3_i := i$

This graph shows how V2/V1 changes as θ3 changes.

$V2_i$	$\theta3_i$
1.58	130
1.509	131
1.443	132
1.38	133
1.321	134
1.265	135
1.211	136
1.16	137
1.112	138
1.066	139
1.021	140
0.979	141
0.938	142
0.899	143
0.862	144
0.826	145
0.791	146
0.757	147
0.725	148
0.693	149
0.663	150

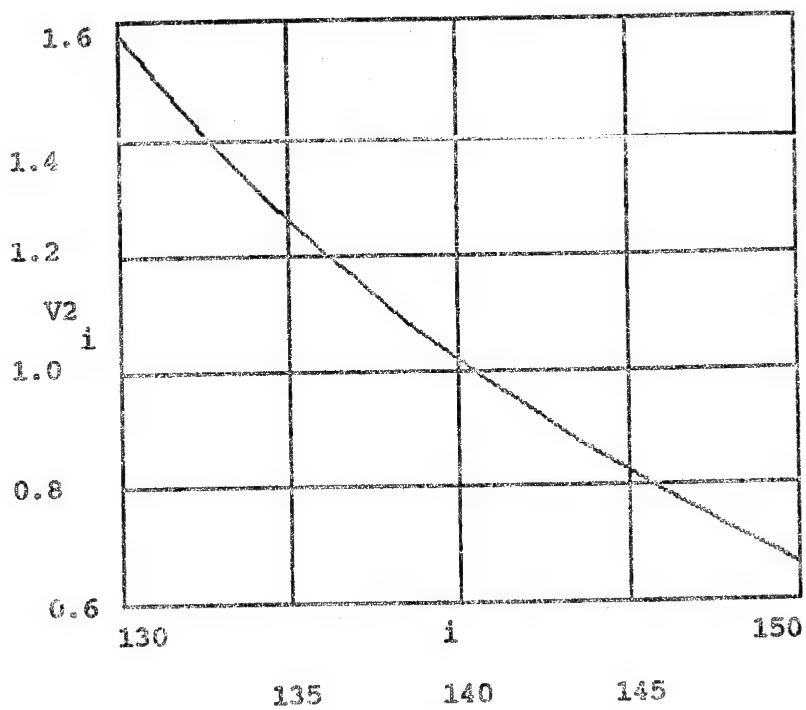


Figure 13-8

Accident No:1, Striation Analysis for θ2 := 112 degrees.

The following shows how the ratio of V2/V1 varies when θ2 :=112 deg, and θ3 is allowed to vary from 130 deg to 150 deg.

$i := 130 ..150$

$\theta 2 := 112$

$\theta 3_i := i$

This graph shows how V2/V1 changes as θ3 changes.

$V2_i$	$\theta 3_i$
2.479	130
2.318	131
2.173	132
2.041	133
1.92	134
1.81	135
1.708	136
1.614	137
1.526	138
1.445	139
1.369	140
1.298	141
1.231	142
1.168	143
1.109	144
1.053	145
1	146
0.95	147
0.902	148
0.856	149
0.812	150

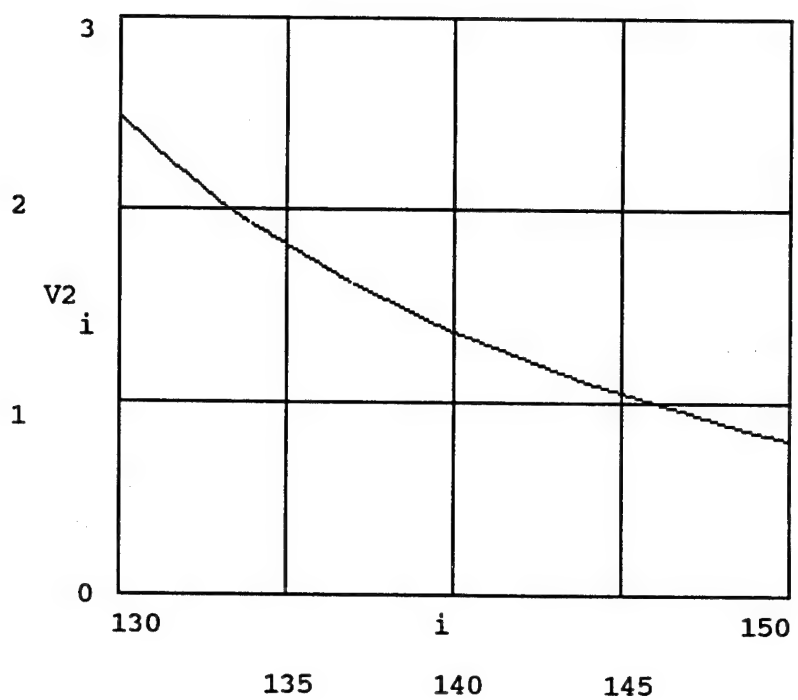


Figure 13-9

Accident No:1, Striation Analysis for $\theta 2 := 123$ degrees.

The following shows how the ratio of V2/V1 varies when $\theta 2 :=123$ deg, and $\theta 3$ is allowed to vary from 130 deg to 150 deg.

$i := 130 \,..150$

$\theta 2 := 123$

$\theta 3_i := i$

This graph shows how V2/V1 changes as $\theta 3$ changes.

$V2_i$	$\theta 3_i$
6.286	130
5.423	131
4.751	132
4.212	133
3.77	134
3.401	135
3.088	136
2.819	137
2.585	138
2.38	139
2.199	140
2.037	141
1.891	142
1.76	143
1.64	144
1.531	145
1.431	146
1.339	147
1.254	148
1.175	149
1.101	150

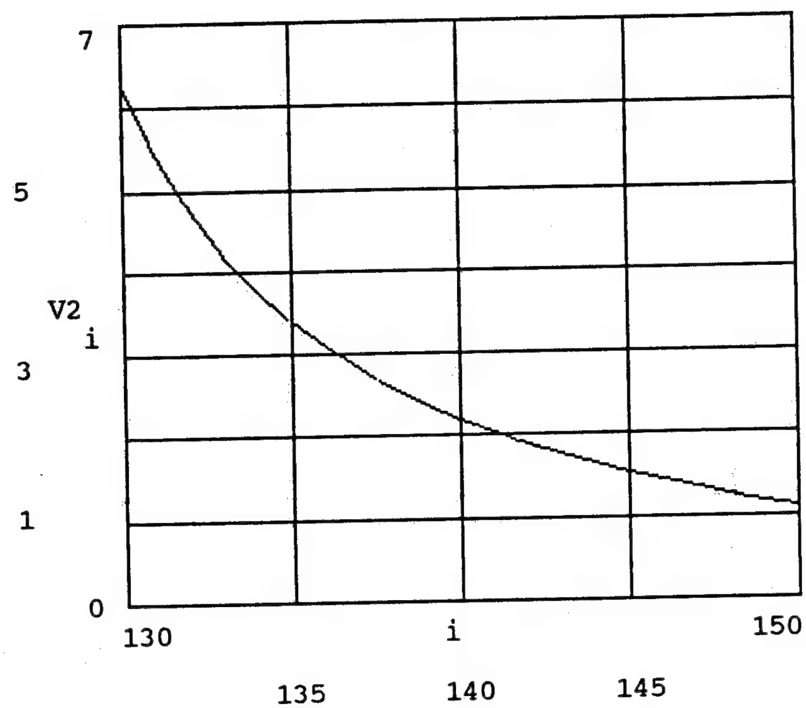
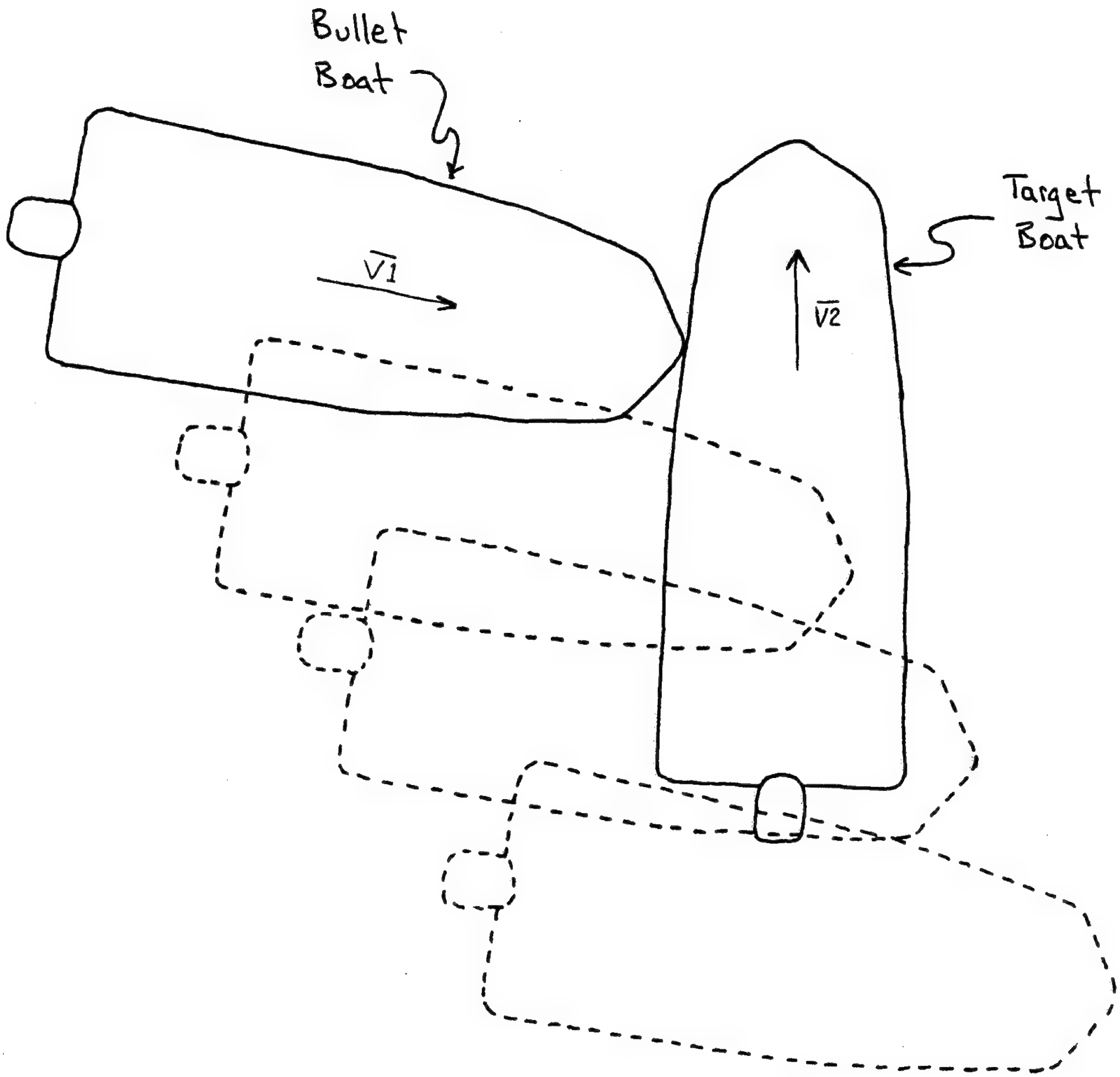


Figure 13-10



Approximate Path of the Bullet Boat Across the Target Boat.

Figure 13-11

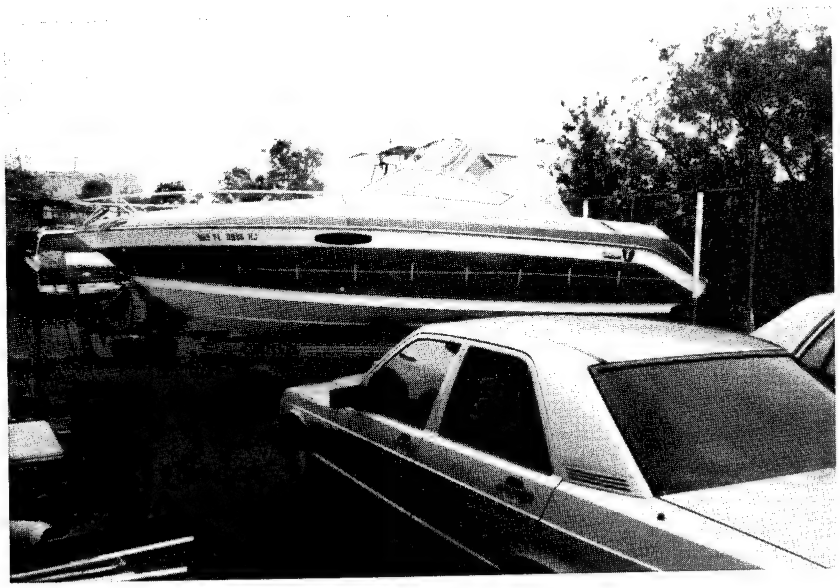


Figure 13-12

Figure 13-13

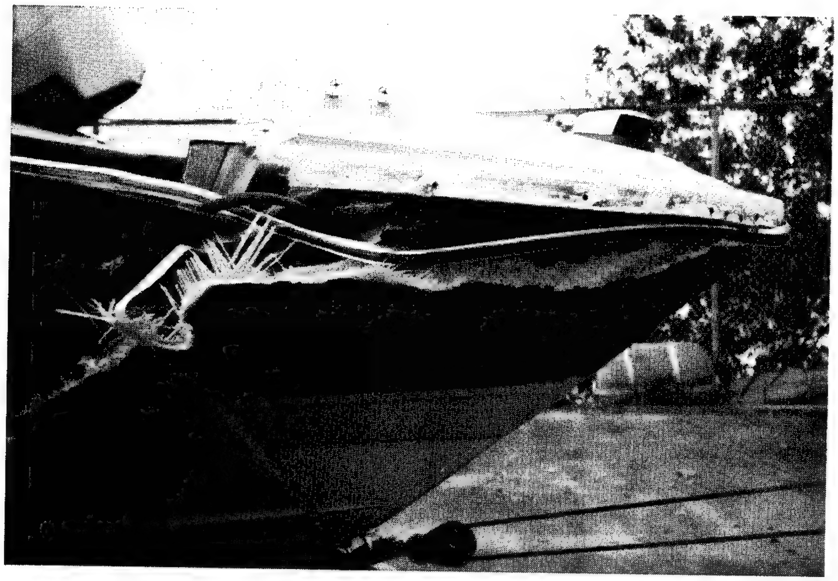


Figure 13-14

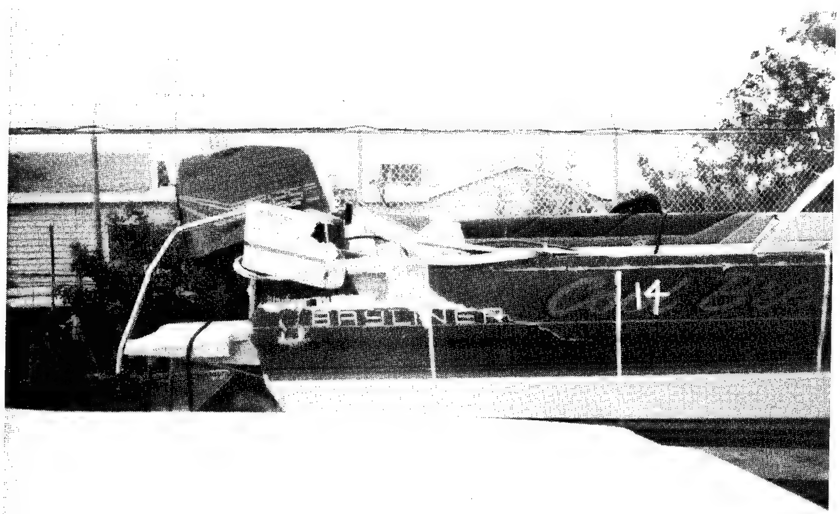


Figure 13-15

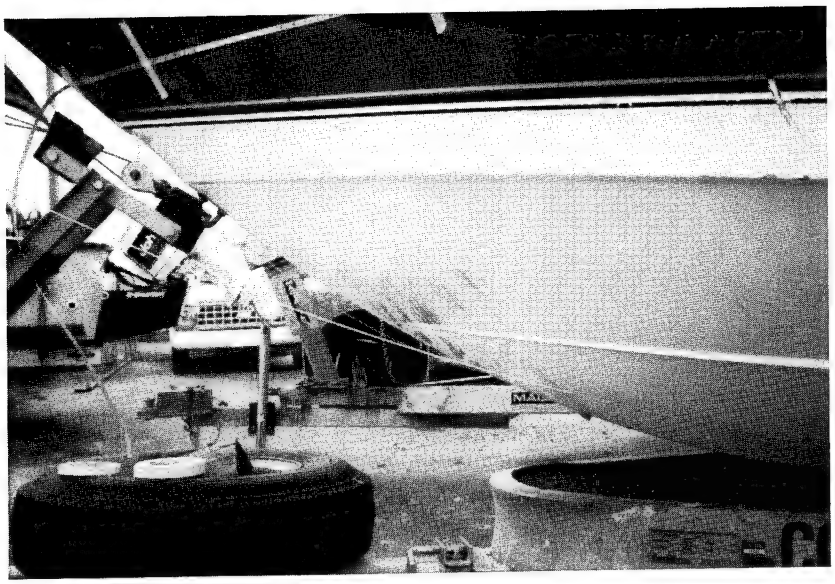
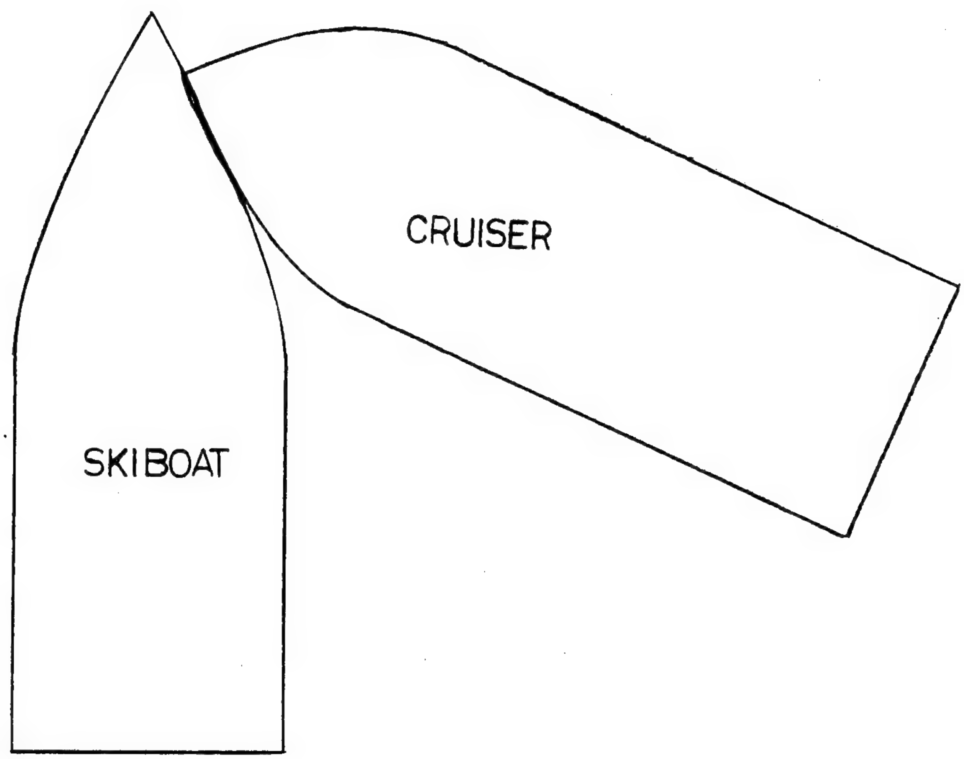


Figure 13-16

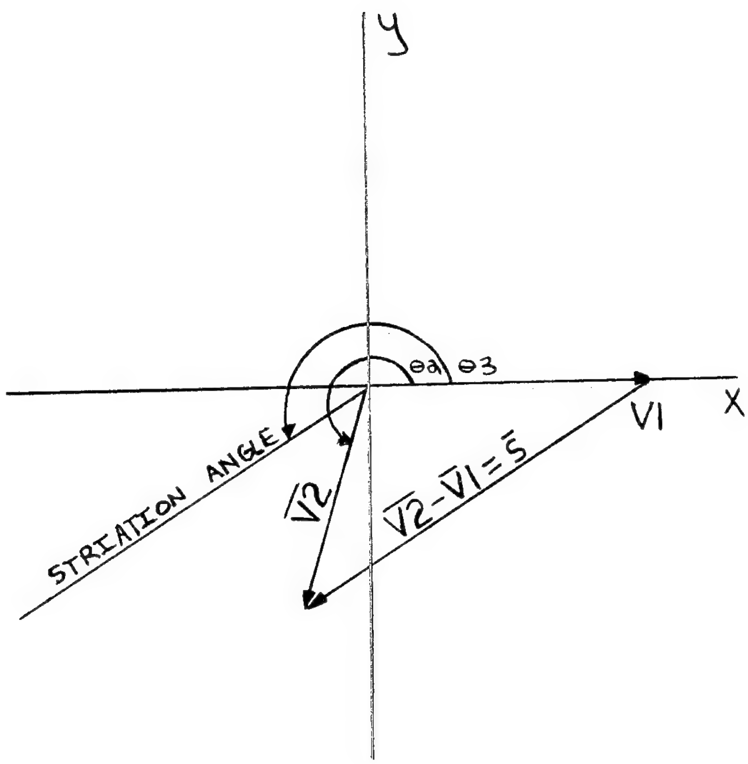


This Diagram Shows How the Striation Marks on the Bow of the Cruiser Might Have Been Made. Note That a Large Area of the Two Boats is in Contact.

Figure 13-17

Velocity Diagram For:

$\theta 3 = 215°$
$\theta 2 = 254°$

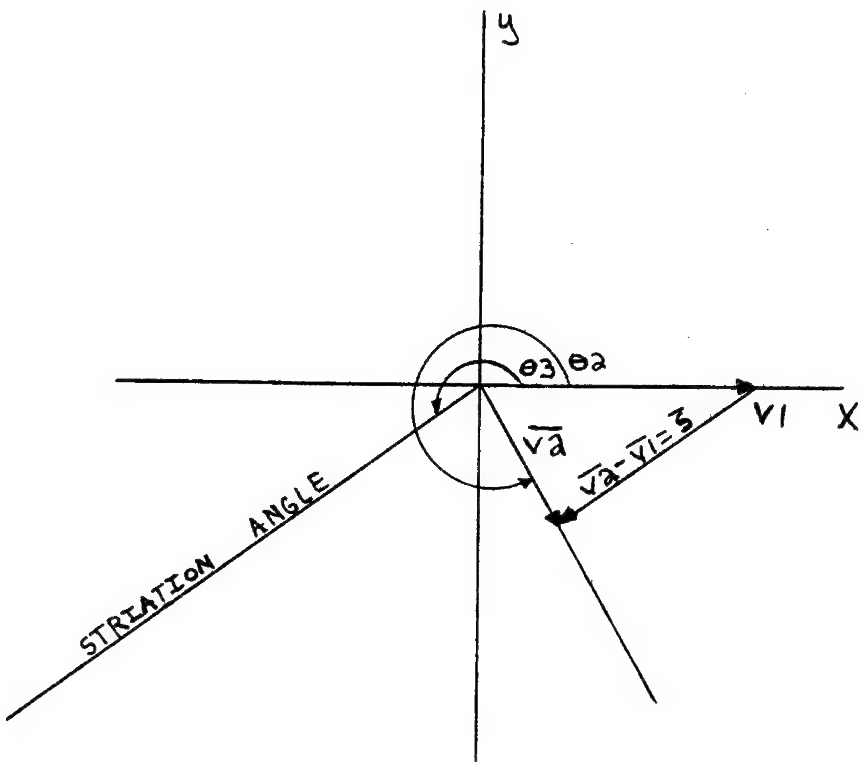


From Figure 13-21, VR = 0.911

Figure 13-18(a)

Velocity Diagram For:

$\theta 3 = 215°$
$\theta 2 = 300°$



From Figure 13-21, VR = 0.576

Figure 13-18(b)

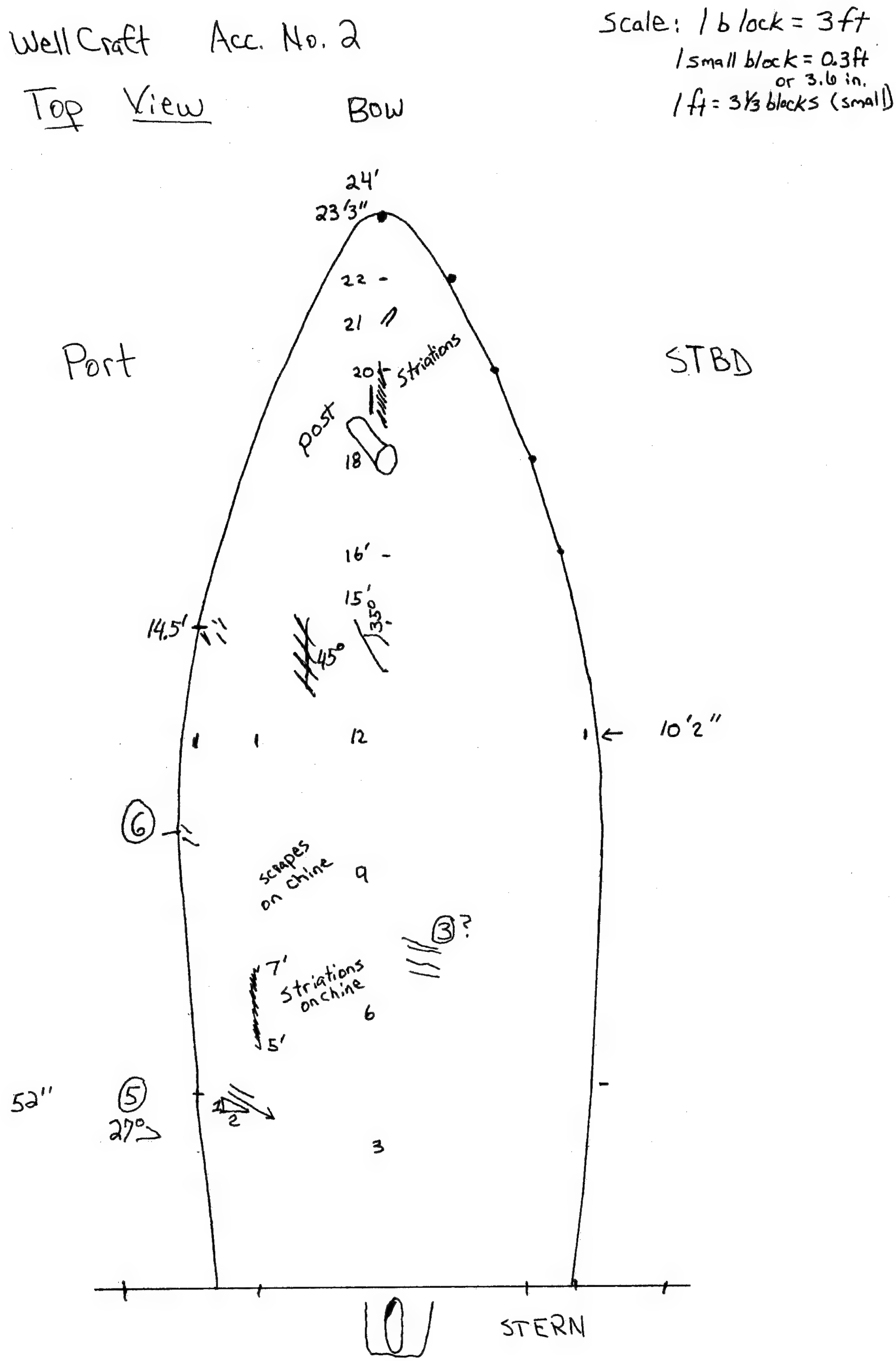
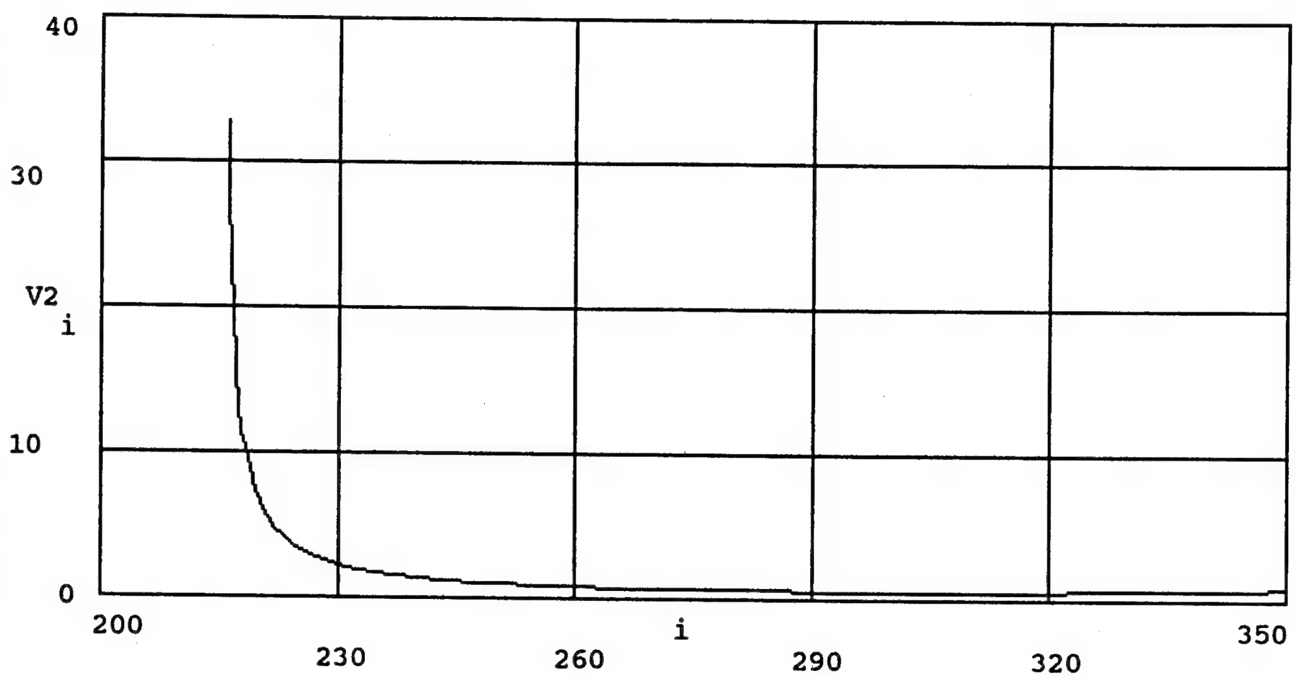

WellCraft Acc. No. 2
Scale: 1 block = 3ft
1 small block = 0.3ft or 3.6 in.
1 ft = 3 1/3 blocks (small)
Top View
Bow
Port
STBD
24'
23'3"
22
21
20
striations
post
18
16'
15'
14.5'
45°
35°
12
10'2"
6
scrapes on chine
9
3?
7'
striations on chine
6
5'
52"
5
27°
2
3
STERN

Figure 13-19

Accident No. 2: Striation Analysis

In this graph we are showing how the velocity ratio changes for a given striation angle. This graph is based on a fixed value of the striation angle. This graph can be used to estimate the impact angle if the Velocity Ratio and striation angles are known. Remember that θ2 is the impact angle, and that θ3 is the striation angle.

θ3 = 215 degrees



This graph shows the velocity ratio for the entire range of possible impact angles. The closer the impact angle is to the striation angle, the higher the value of the velocity ratio. The graph becomes undefined when θ2 = θ3.

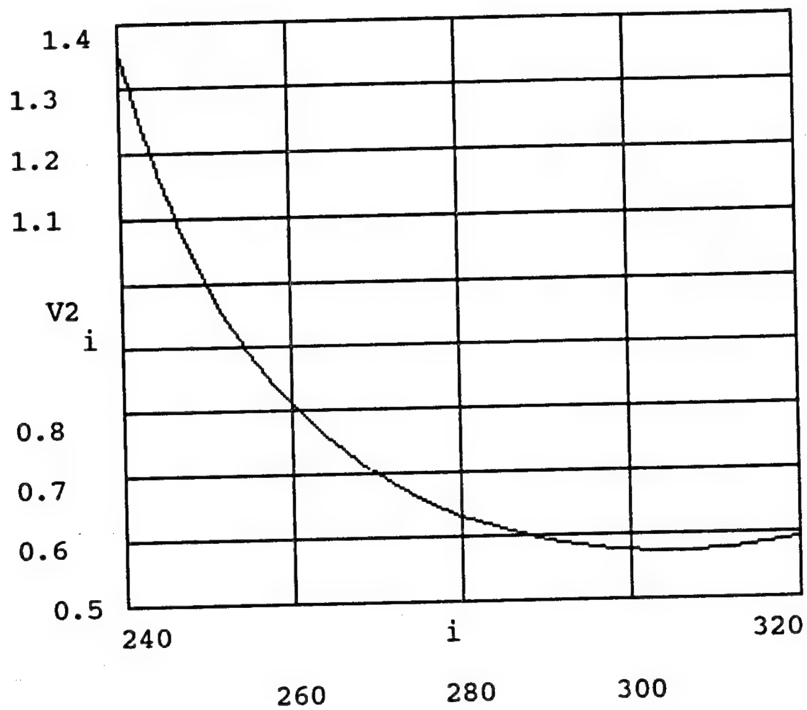
Figure 13-20

Accident No. 2: Striation Analysis

In this graph we are showing how the velocity ratio changes for a given striation angle. This graph is based on a fixed value of the striation angle. This graph can be used to estimate the impact angle if the Velocity Ratio and striation angles are known. Remember that θ2 is the impact angle, and that θ3 is the striation angle.

$\theta 3 = 215$ degrees

$V2_i$	$\theta 2_i$
1.357	240
1.263	242
1.183	244
1.114	246
1.053	248
1	250
0.953	252
0.911	254
0.874	256
0.841	258
0.811	260
0.784	262
0.76	264
0.738	266
0.718	268
0.7	270
0.684	272
0.669	274
0.656	276
0.644	278
0.633	280
0.623	282
0.614	284
0.607	286
0.6	288
0.594	290
0.589	292
0.584	294
0.581	296
0.578	298
0.576	300
0.574	302
0.574	304
0.574	306
0.574	308
0.576	310
0.578	312
0.581	314
0.584	316
0.589	318
0.594	320



In this graph, i represents the range of possible impact angles (not striation angles).

Figure 13-21

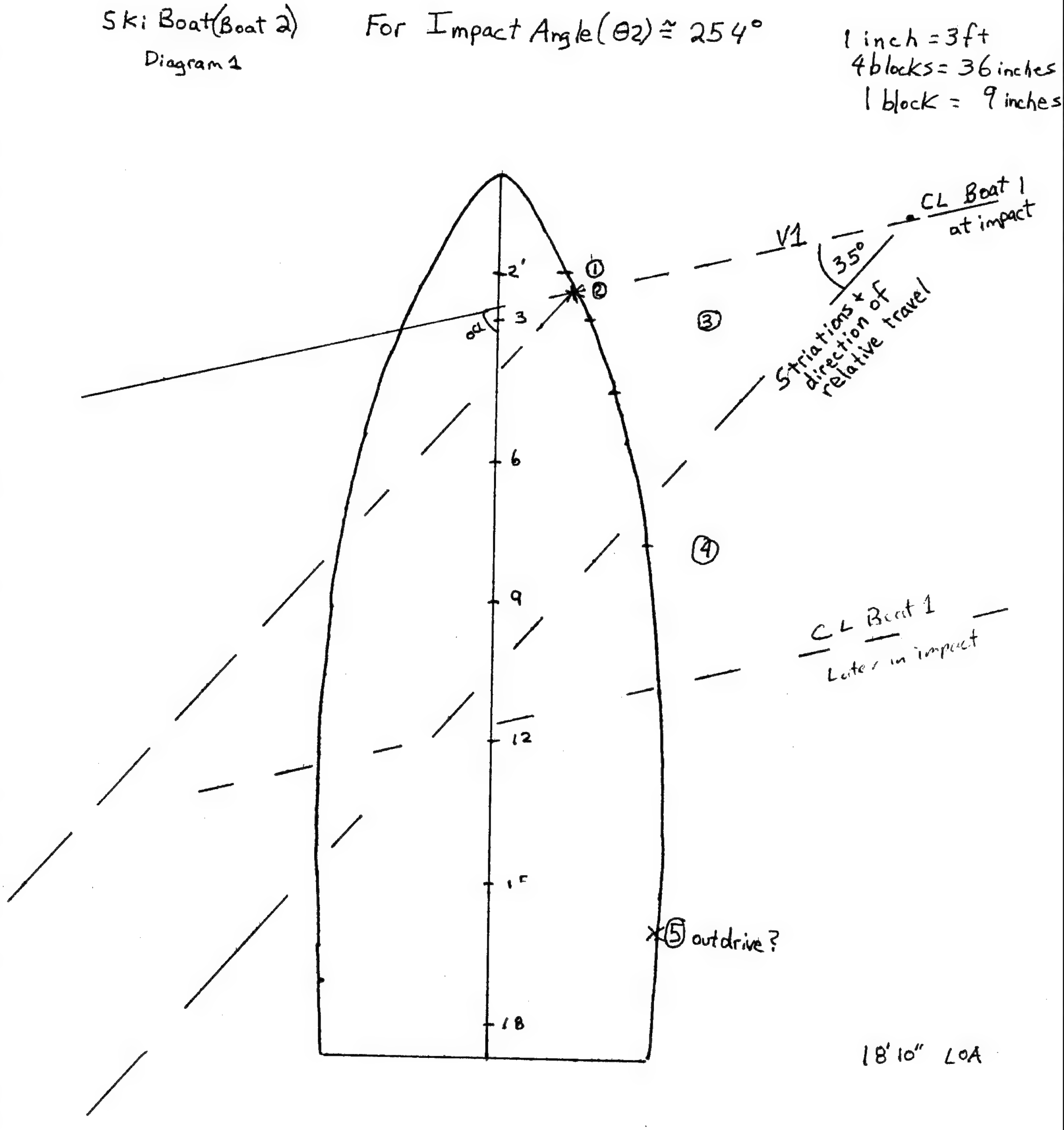

Ski Boat (Boat 2)
Diagram 1
For Impact Angle (θ2) ≅ 254°
1 inch = 3ft
4 blocks = 36 inches
1 block = 9 inches
CL Boat 1
at impact
V1
35°
Striations & direction of relative travel
2'
3
α
1
2
3
6
4
9
CL Boat 1
Later in impact
12
15
5 outdrive?
18
18'10" LOA

Figure 13-22

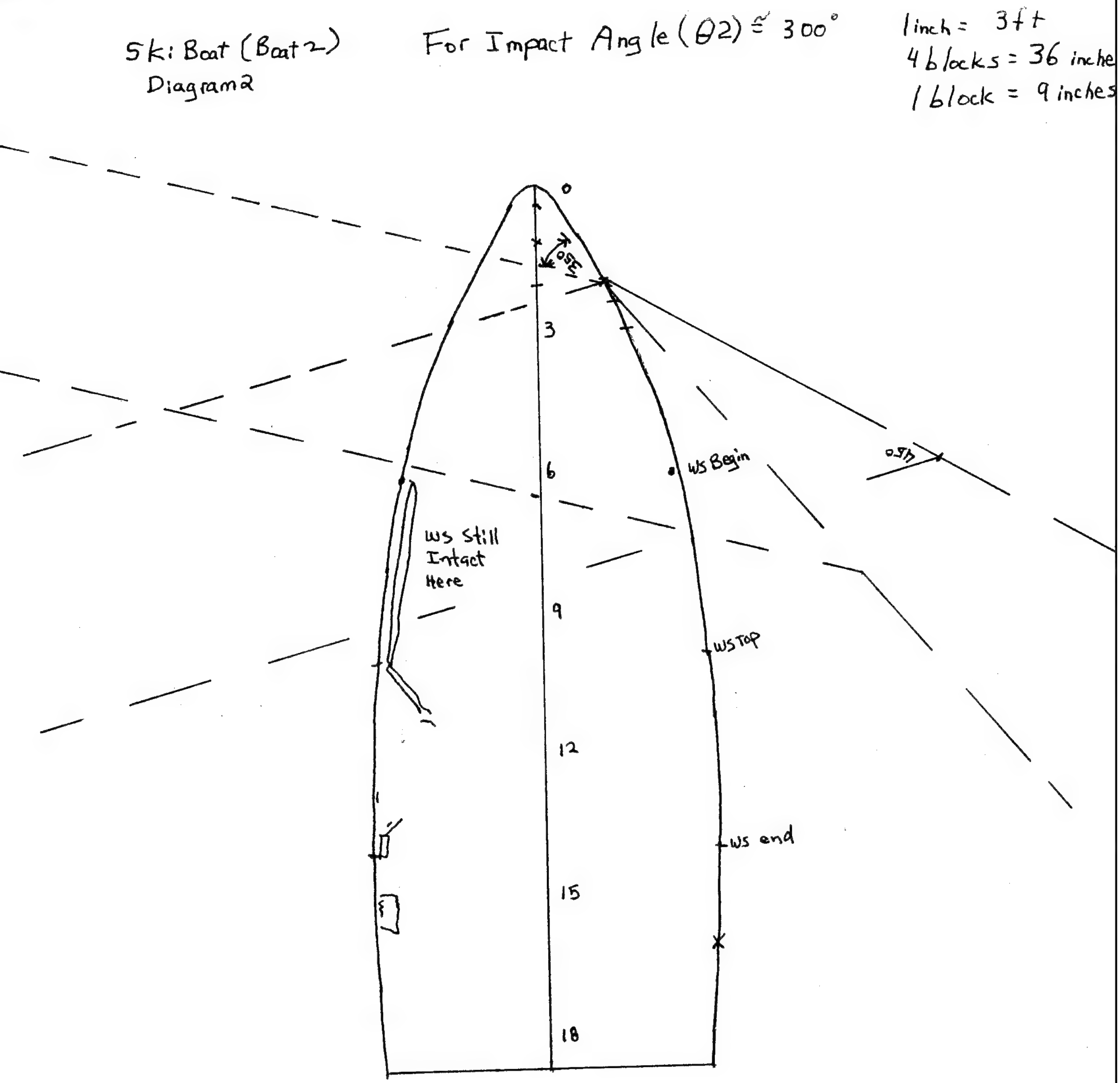

Ski Boat (Boat 2)
Diagram 2
For Impact Angle (θ2) ≅ 300°
1 inch = 3 ft
4 blocks = 36 inches
1 block = 9 inches
0
3
6
9
12
15
18
WS Begin
WS Still
Intact
Here
WS Top
WS end

Figure 13-23

Figure 13-24

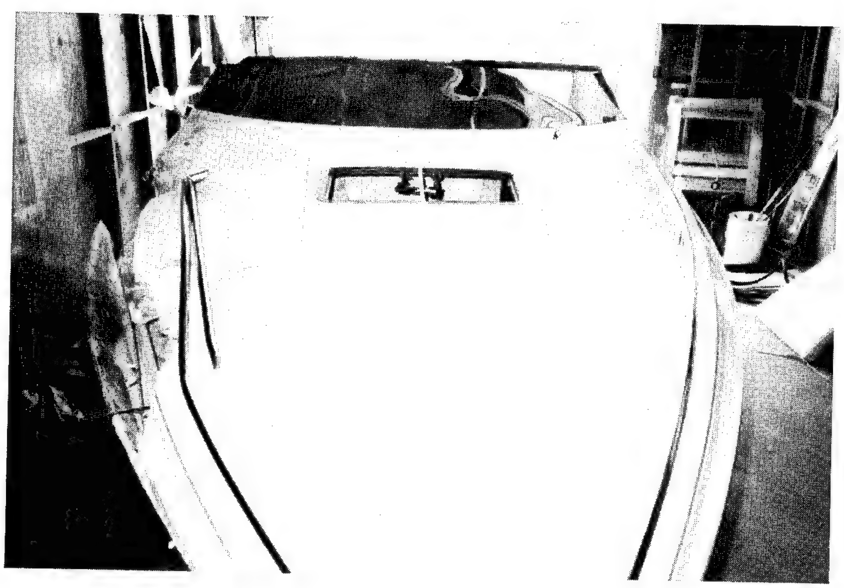


Figure 13-25

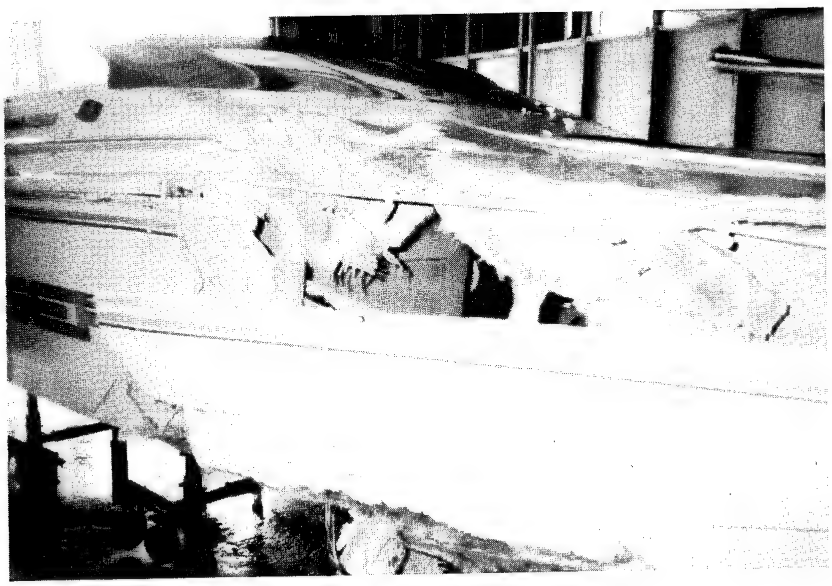
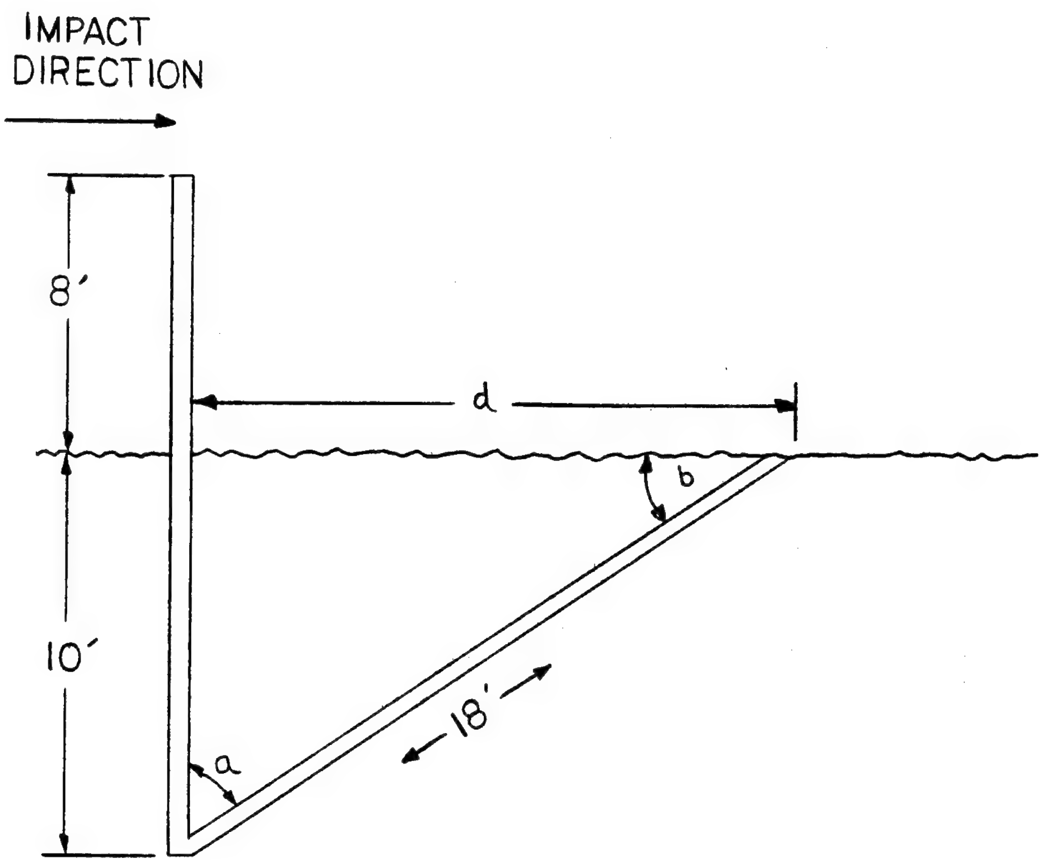


Figure 13-26

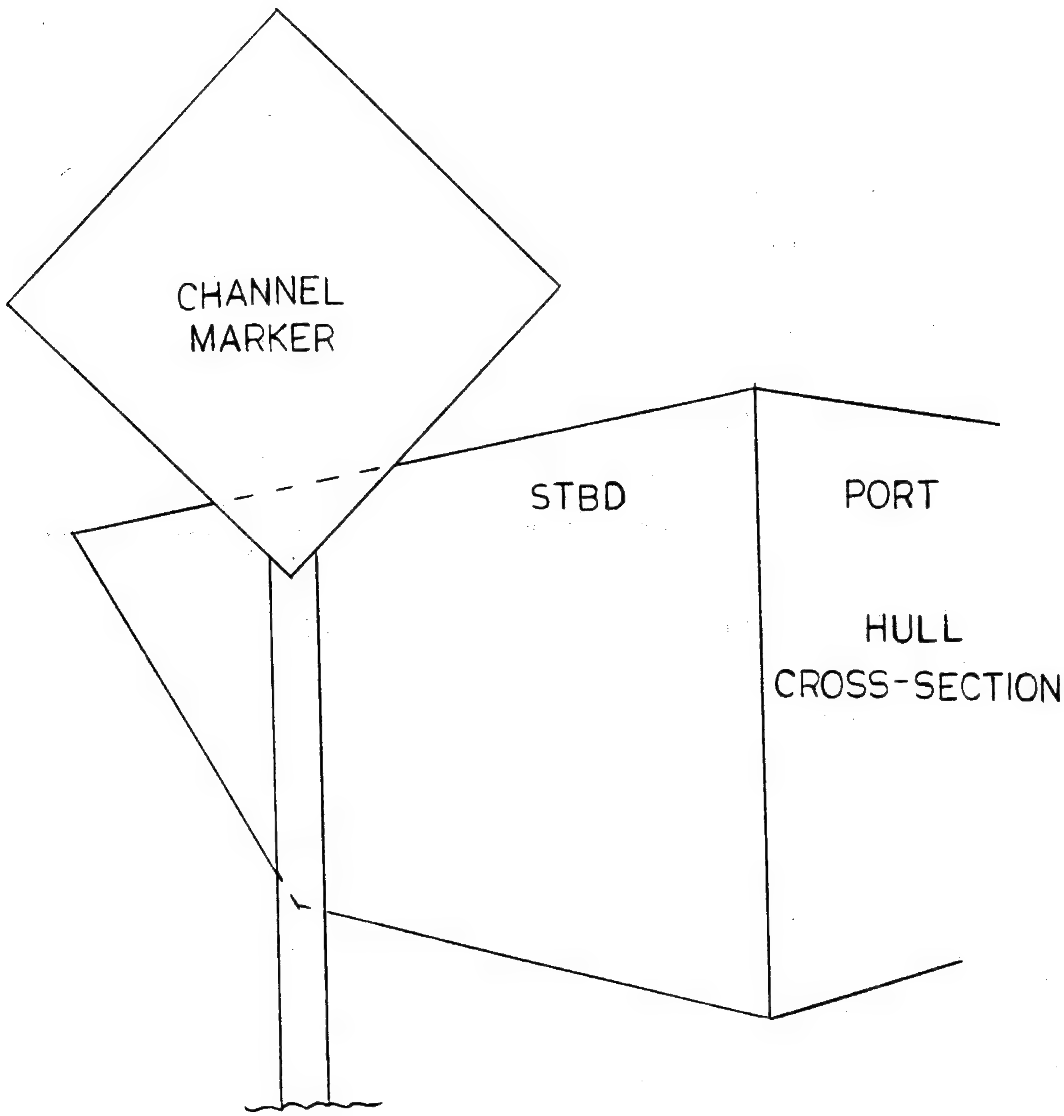


$\sin b = 10'/18'$
$\sin b = 0.556$
$\measuredangle b = 33.7°$
$\measuredangle a = 56.25°$

$d = 18 \cos b$
$d = 18 (\cos 33.7°)$
$d = 14.98'$
$d \cong 15'$

Estimating Distance The I-Beam Traveled

Figure 13-27

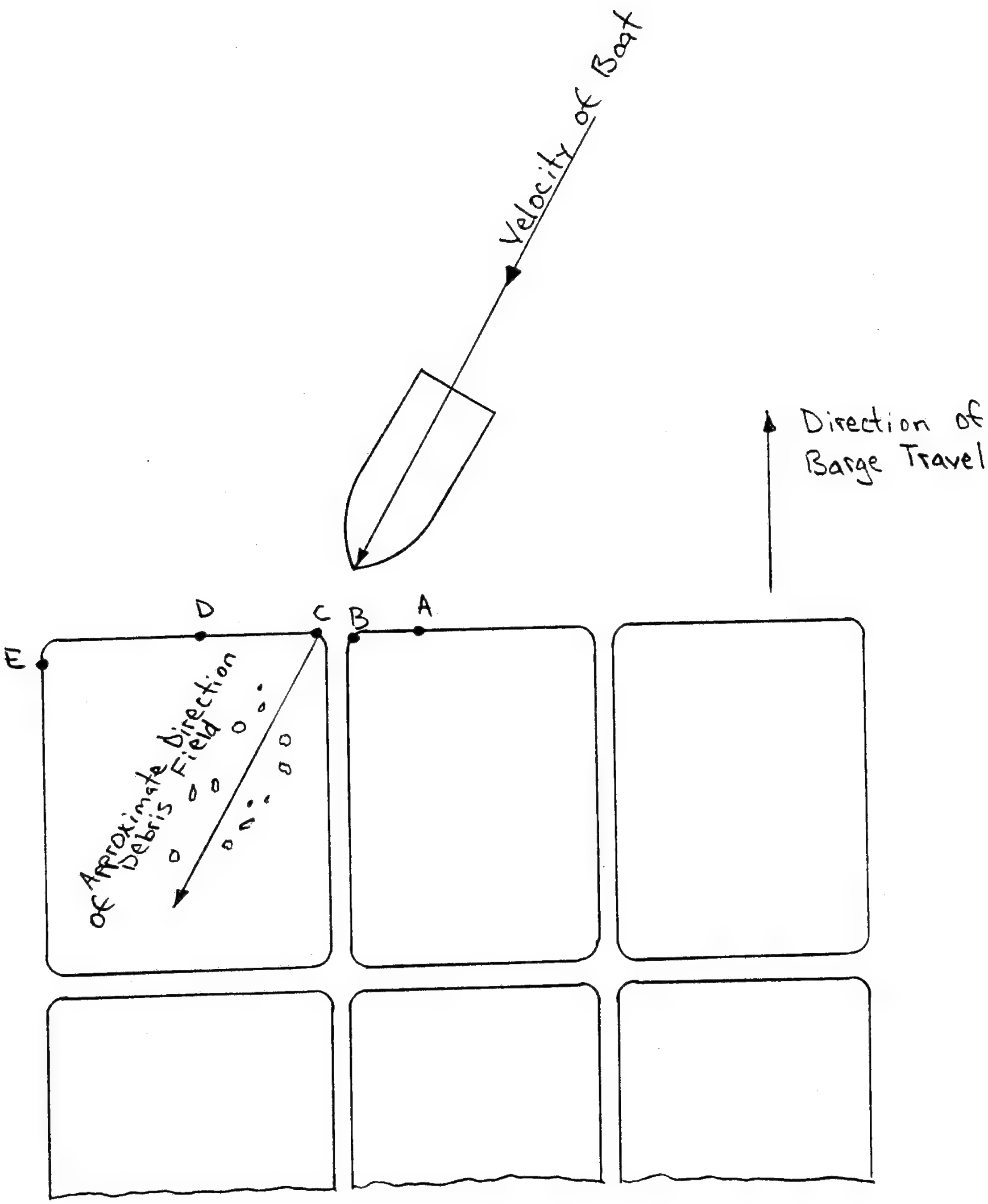


VIEW FROM BOW LOOKING AFT

This Diagram Shows How a Scale Drawing of Both the Boat and the Channel Marker Could Be Used to Determine the Orientation Between the Two.

Figure 13-28

Figure 13-29



(NOT TO SCALE)

Accident No. 4.

Figure 13-30

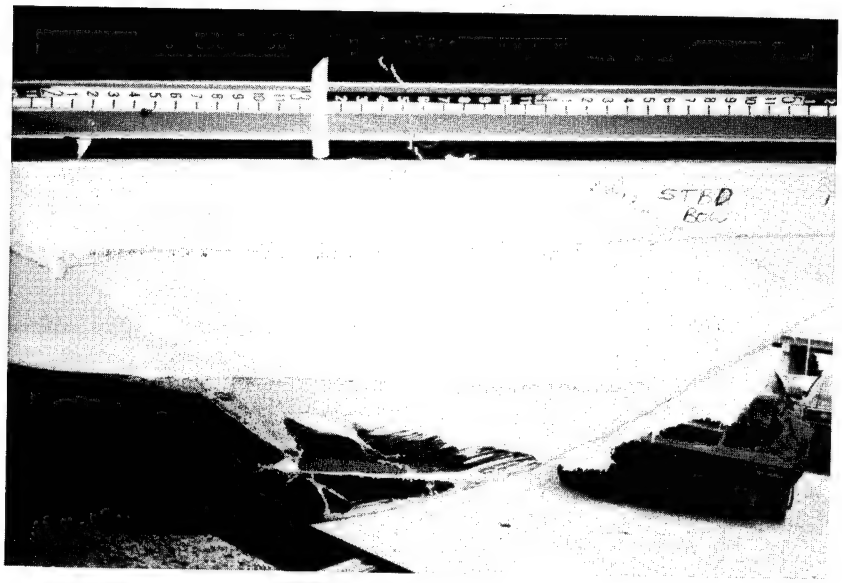


Figure 13-31

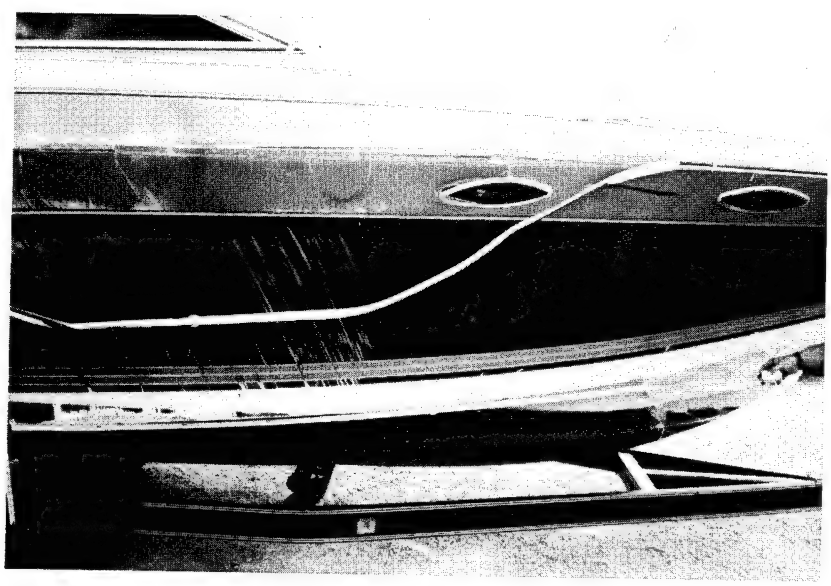


Figure 13-32

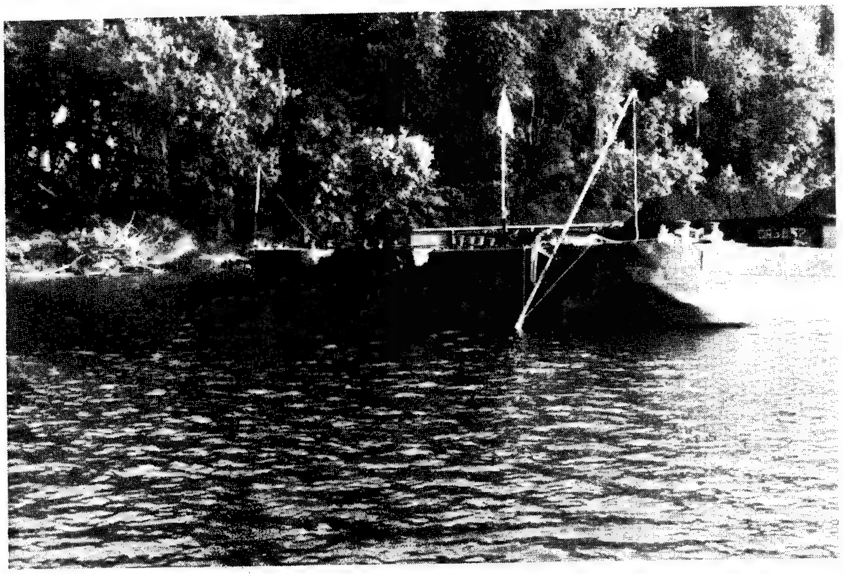


Figure 13-33

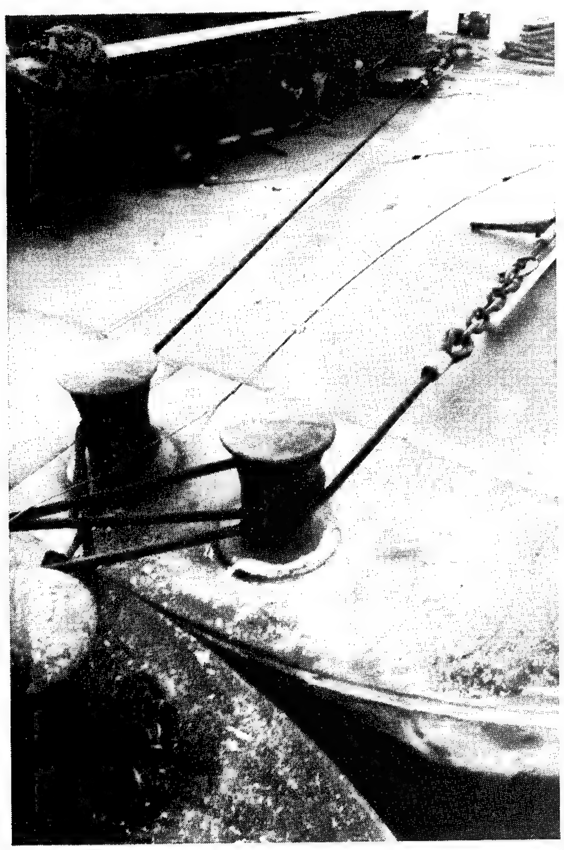
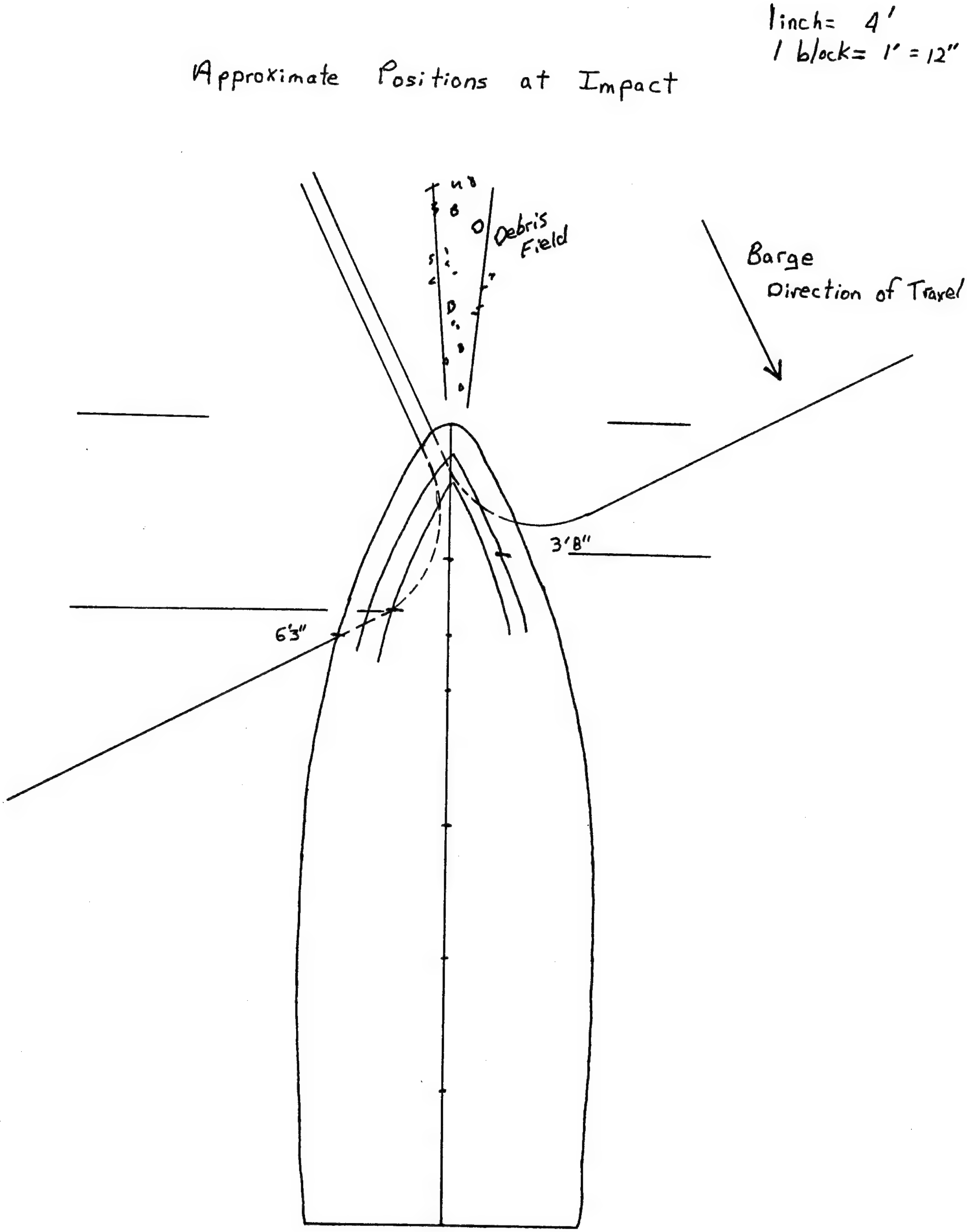


Figure 13-34



This Diagram Shows How Much of the Barge May Have Penetrated the Hull.

Figure 13-35

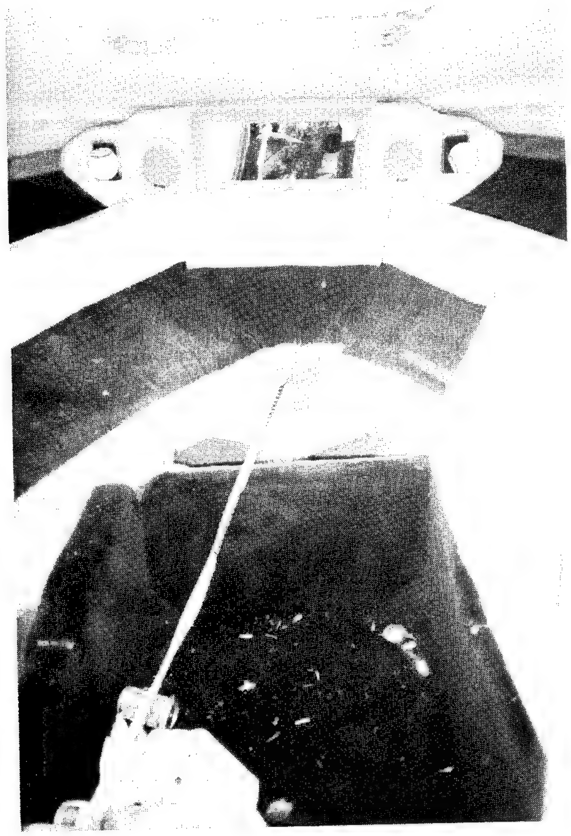


Figure 13-36

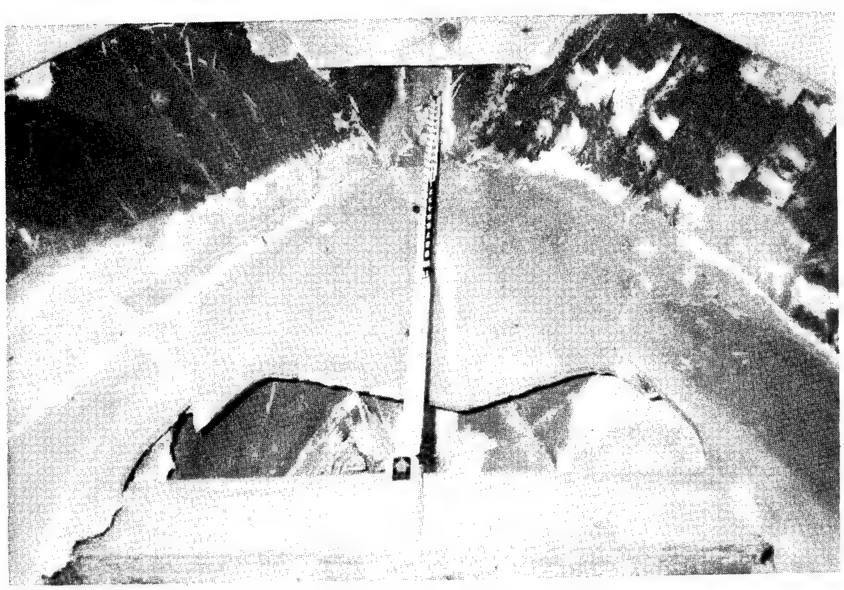


Figure 13-37

Figure 13-38

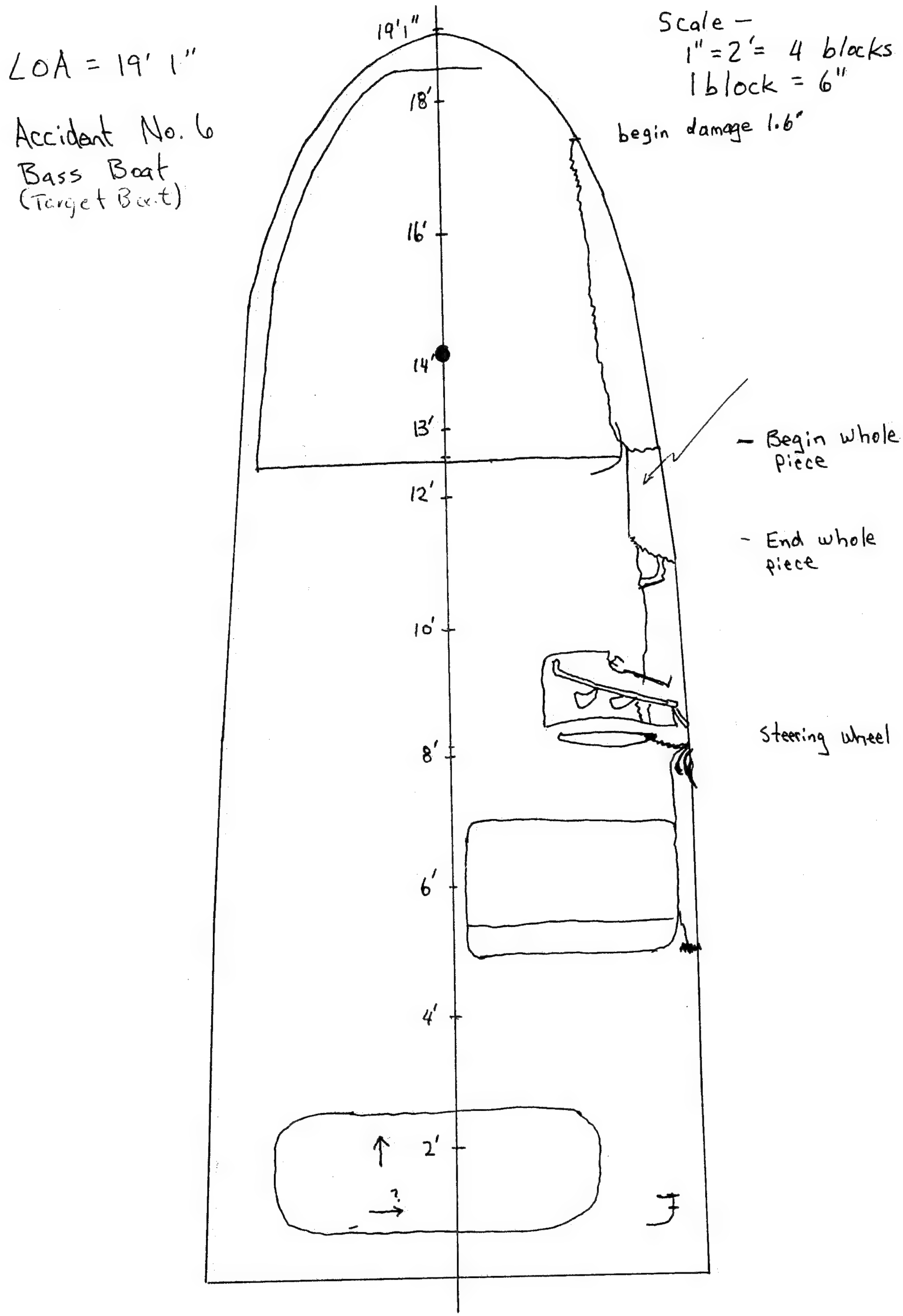

LOA = 19' 1"
Accident No. 6
Bass Boat
(Target Boat)
Scale –
1" = 2' = 4 blocks
1 block = 6"
begin damage 1.6"
19'1"
18'
16'
14'
13'
12'
10'
8'
6'
4'
2'
– Begin whole piece
– End whole piece
Steering wheel

Figure 13-39

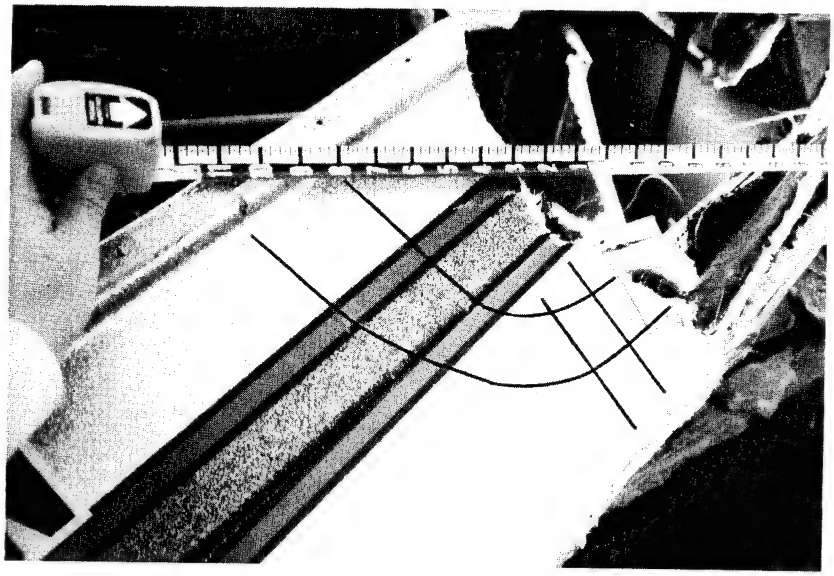


Figure 13-40

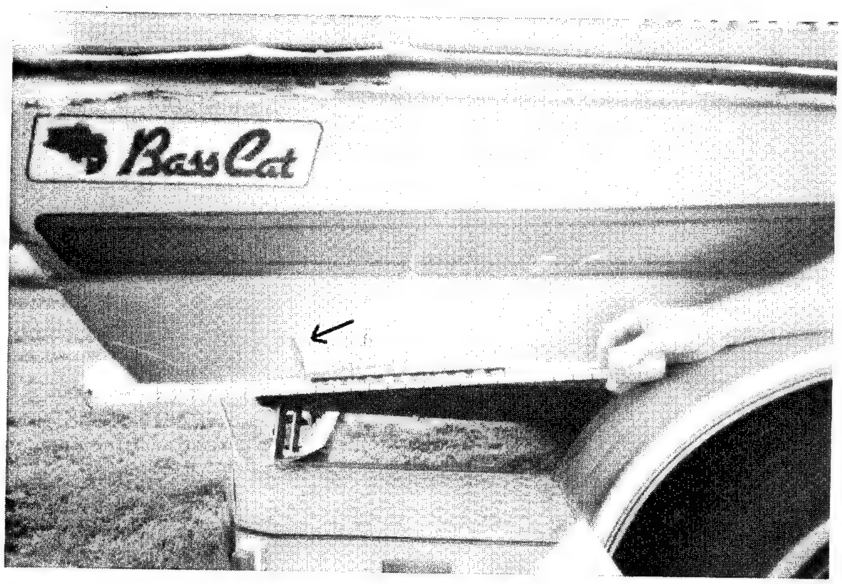
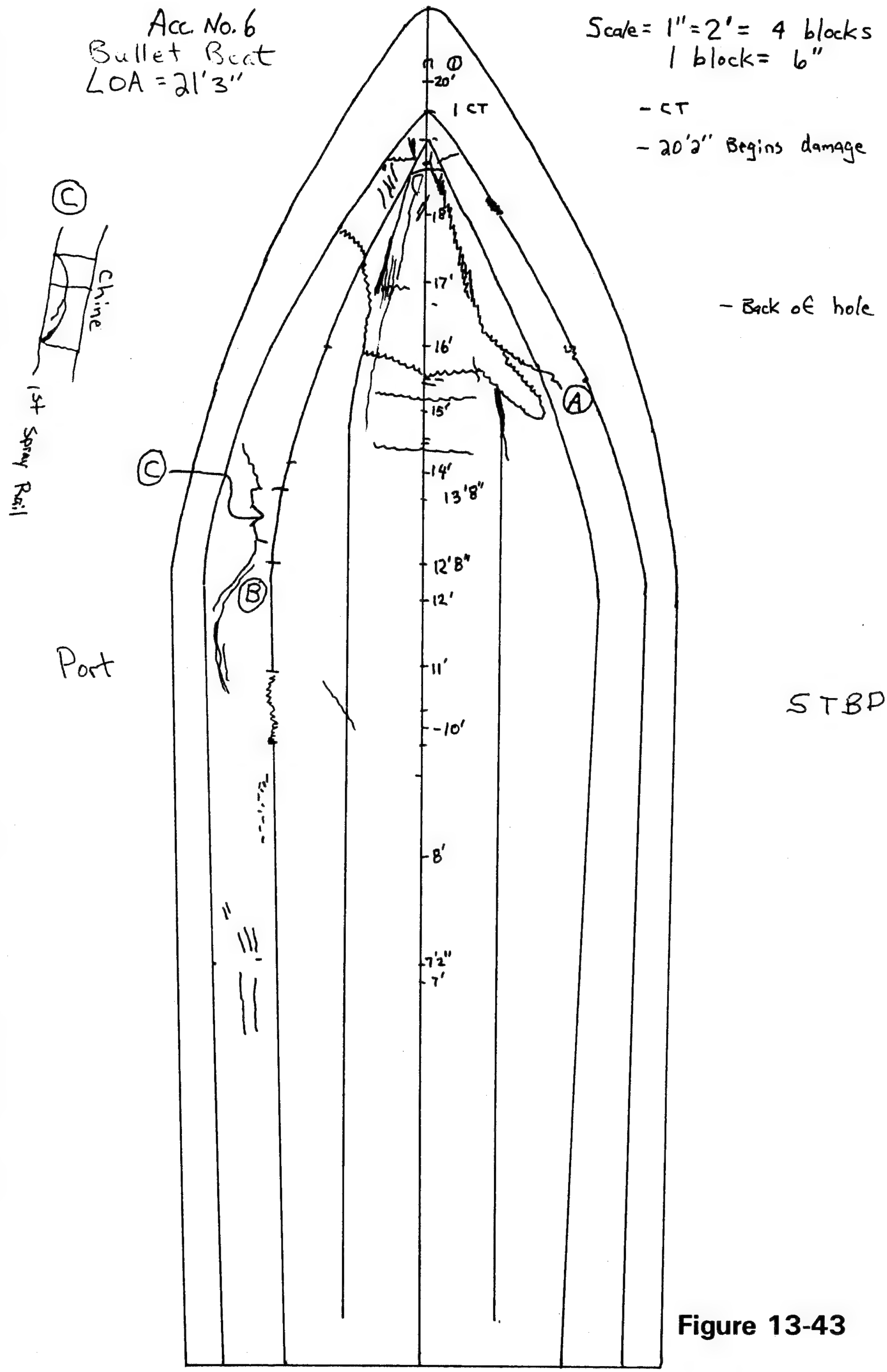


Figure 13-41

Figure 13-42



Acc. No. 6
Bullet Boat
LOA = 21'3"
Scale = 1" = 2' = 4 blocks
1 block = 6"
1 CT
- CT
- 20'2" Begins damage
- Back of hole
20'
18'
17'
16'
15'
14'
13'8"
12'8"
12'
11'
10'
8'
7'2"
7'
A
B
C
Chine
1st Spray Rail
Port
STBD

Figure 13-43

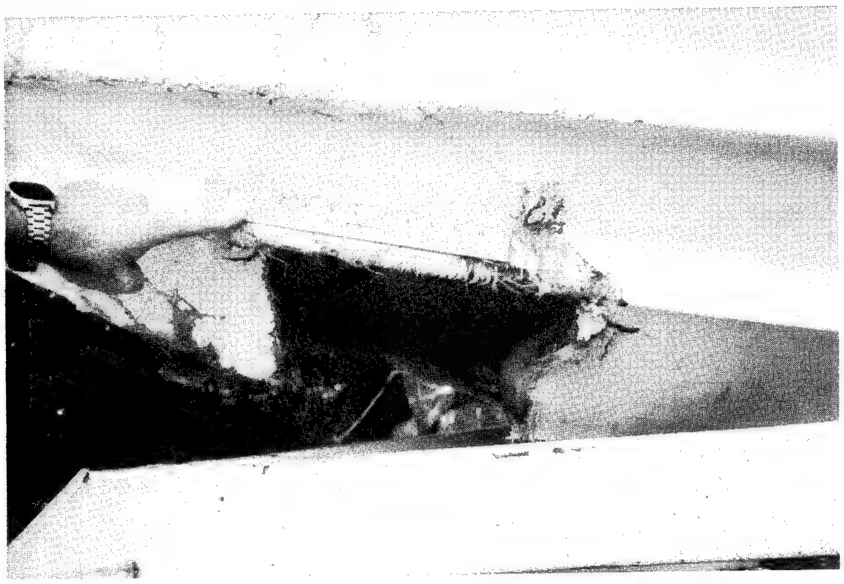
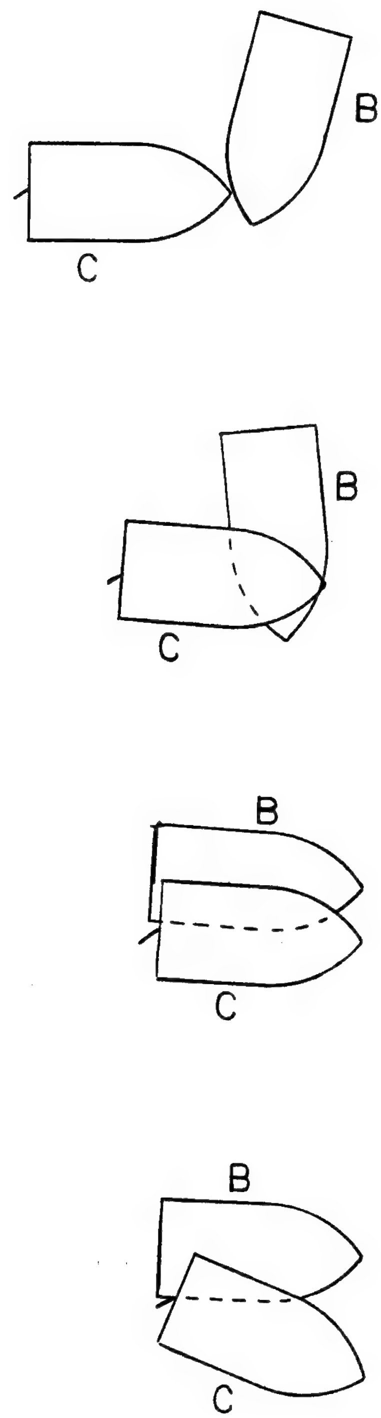


Figure 13-44

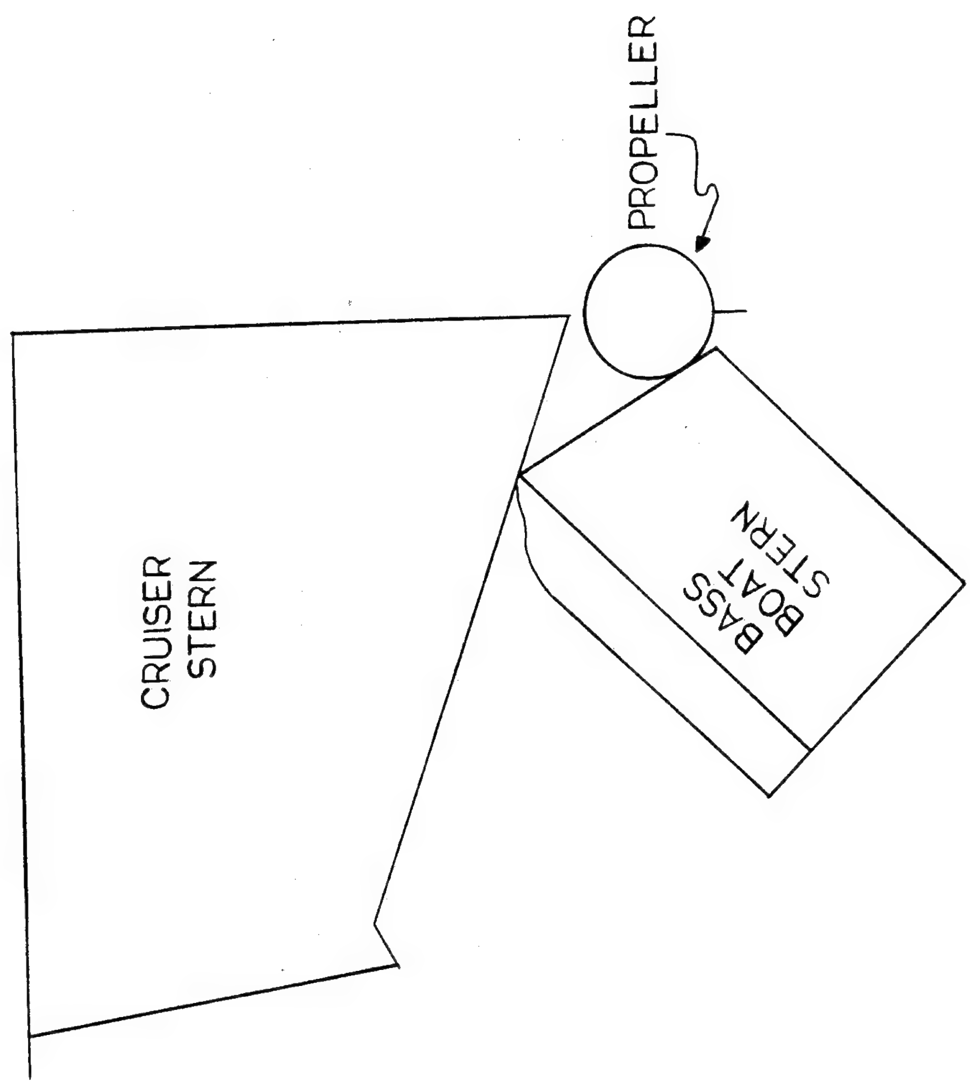
B = Bass Boat
C = Cruiser



Accident No. 6
Possible Accident Scenario

Figure 13-45

Accident No. 6



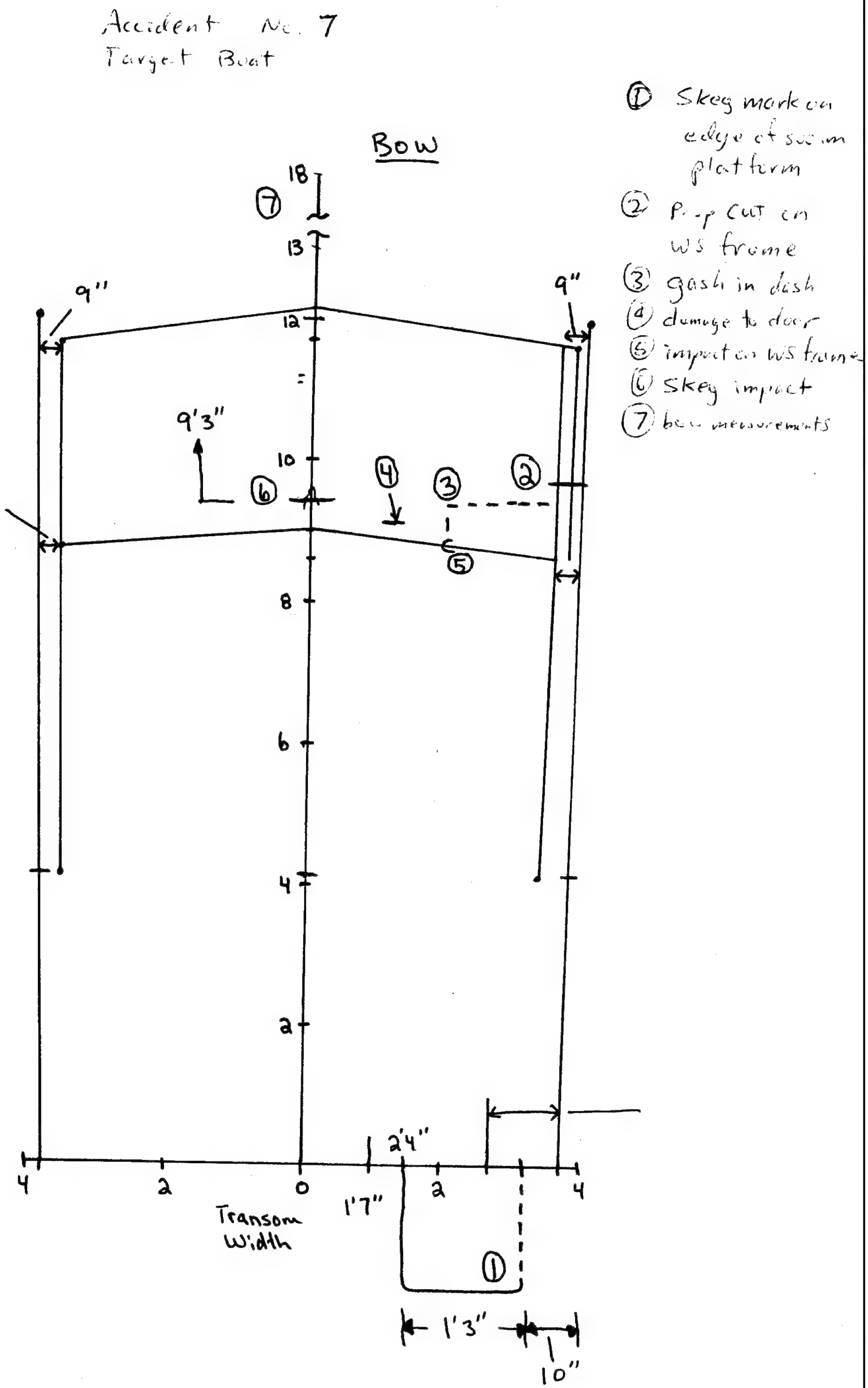
This Diagram Shows the Relative Orientation Required for the Two Boats to Come in Contact with the Propeller of the Cruiser Striking the Bass Boat.

Figure 13-46

Figure 13-47

Figure 13-48

Figure 13-49



Accident No. 7
Target Boat
BOW
① Skeg mark on edge of swim platform
② Prop cut on WS frame
③ gash in dash
④ damage to door
⑤ impact on WS frame
⑥ Skeg impact
⑦ bow measurements
18
13
12
10
8
6
4
2
9"
9"
9'3"
2'4"
1'7"
1'3"
10"
Transom Width

Figure 13-50

Accident No 7.
Target Boat

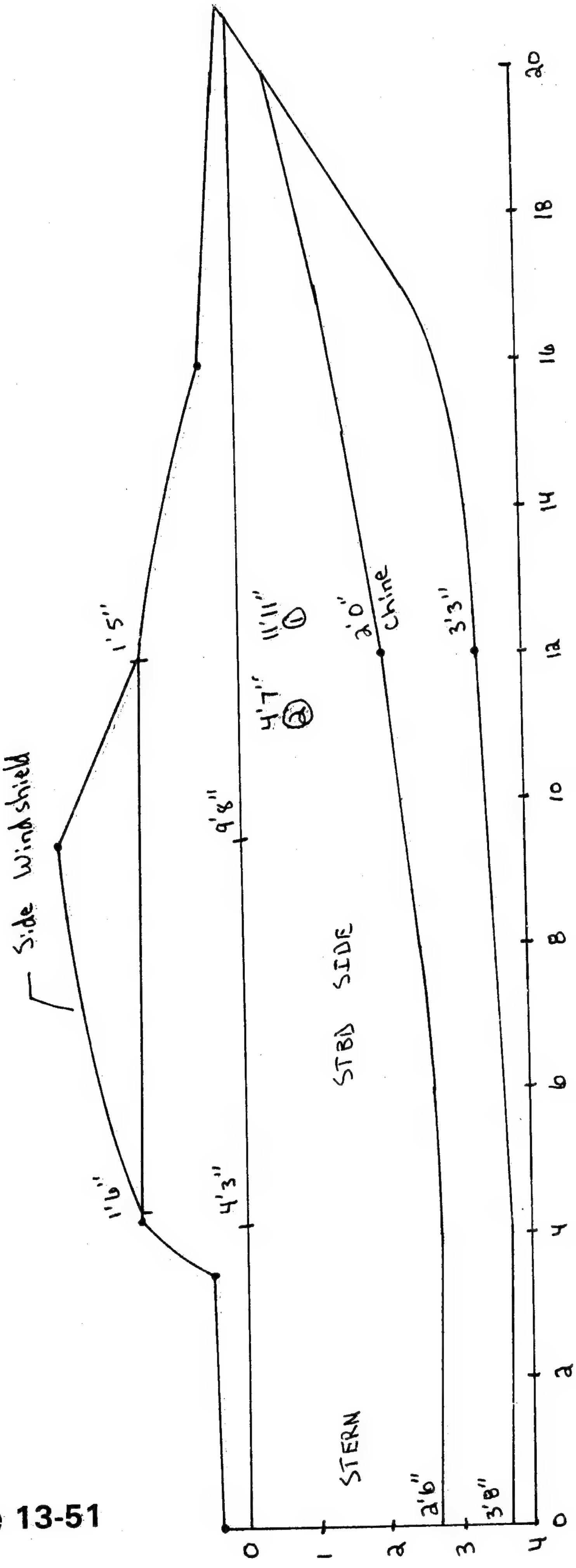
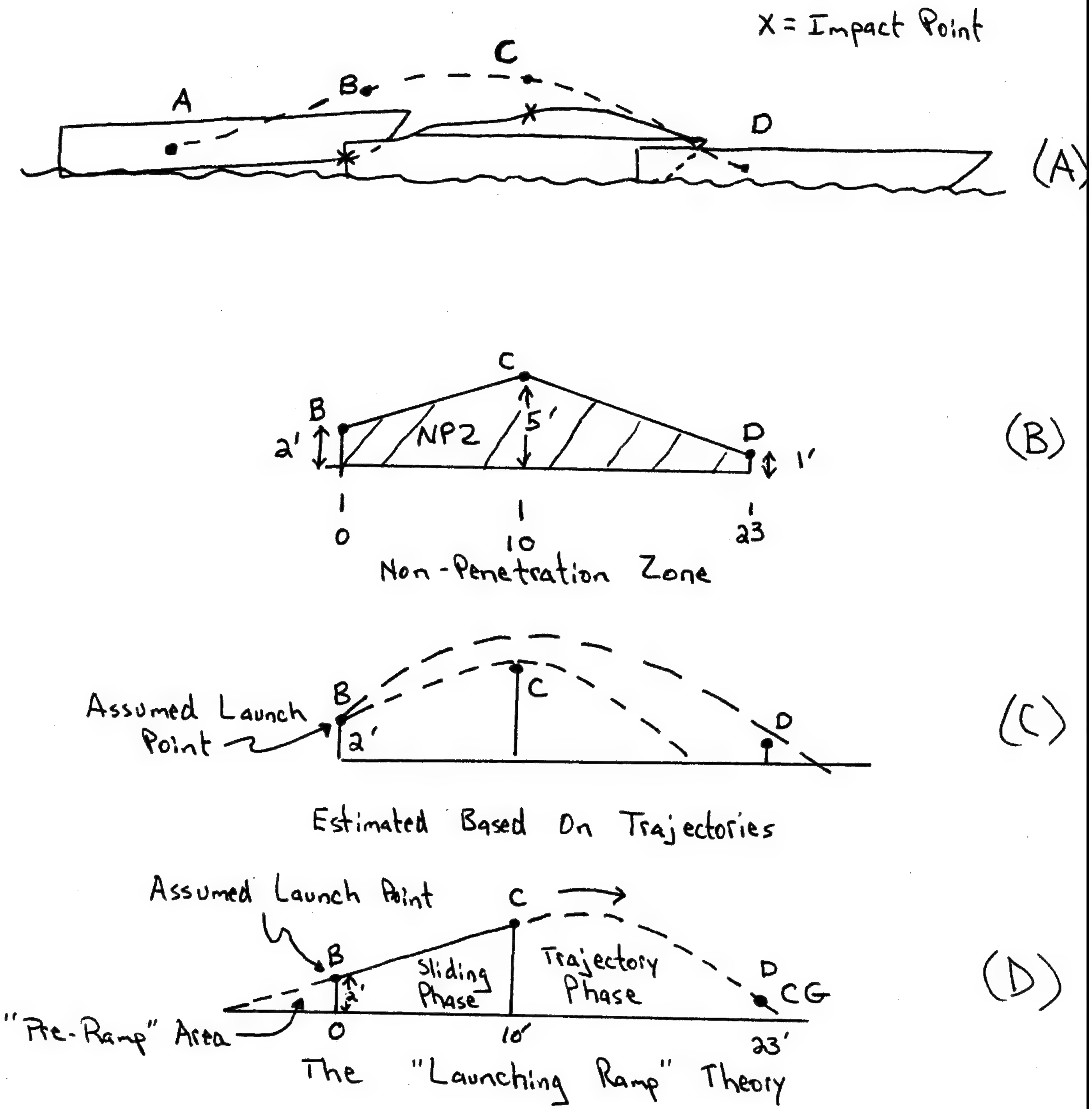


Figure 13-51

Accident No. 7
Non-Penetration Zone



Different Methods of Estimating Speed for an
Over-Ride Collision.

Figure 13-52

Figure 13-53

Figure 13-54

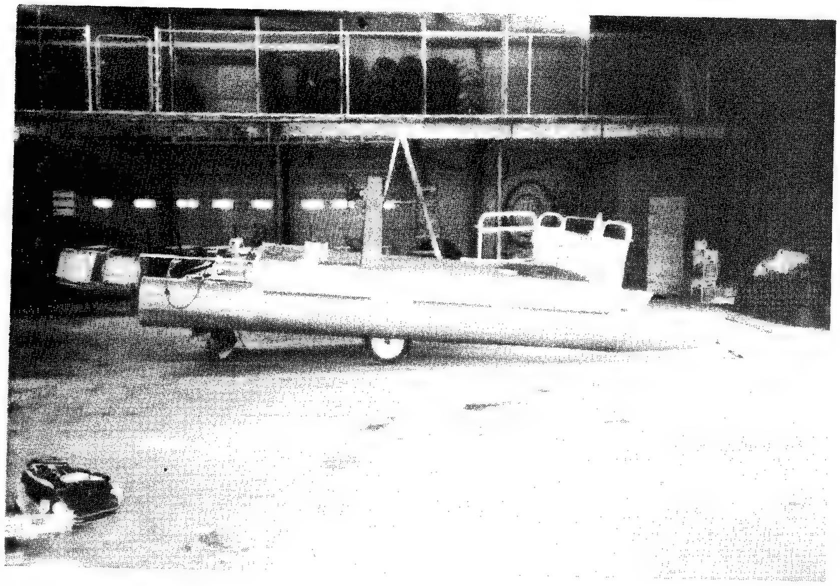


Figure 13-55

Figure 13-56

Figure 13-57

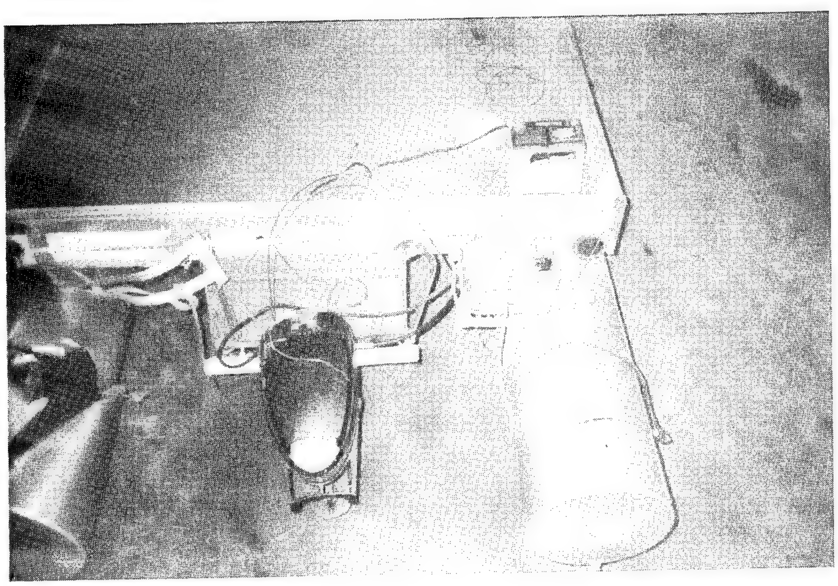


Figure 13-58

Figure 13-59

Figure 13-60

Figure 13-61

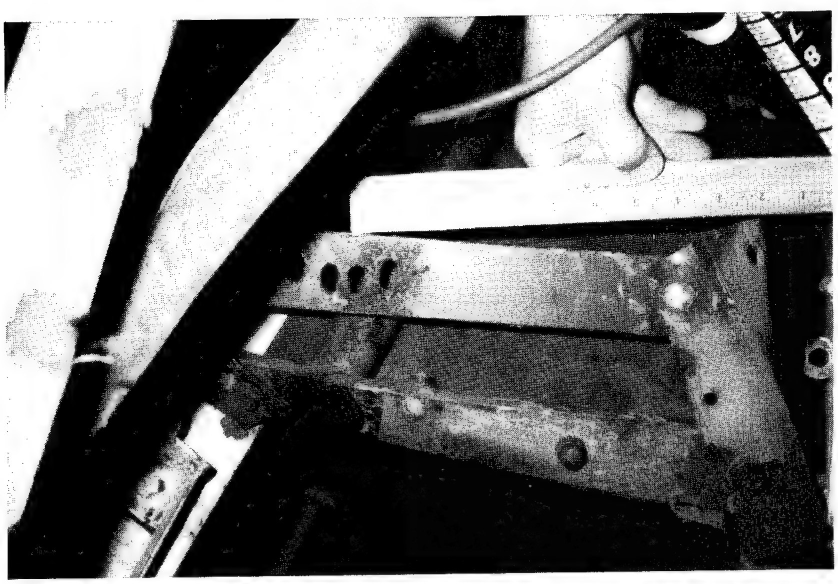


Figure 13-62

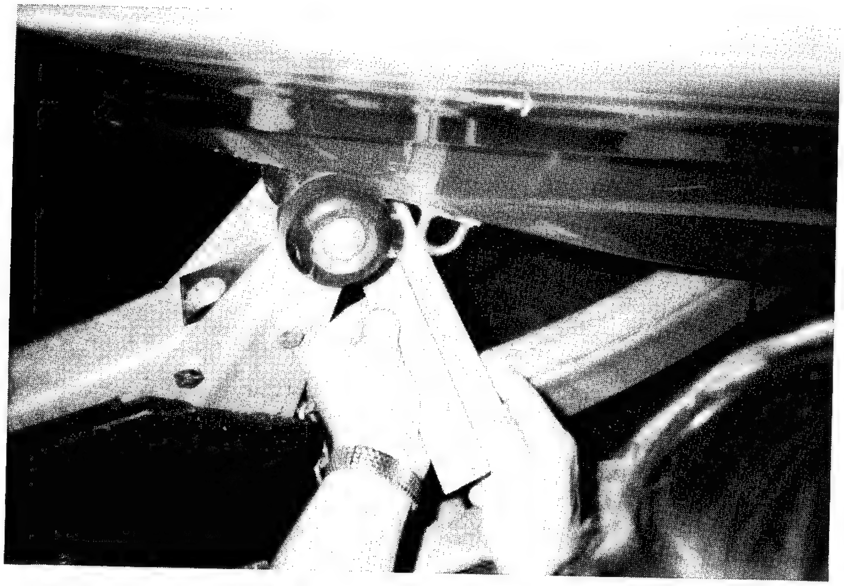


Figure 13-63

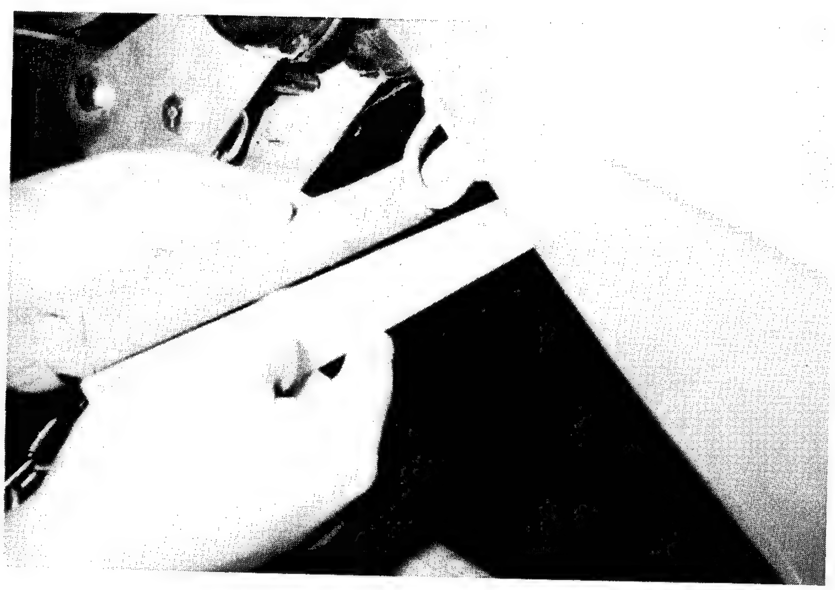


Figure 13-64

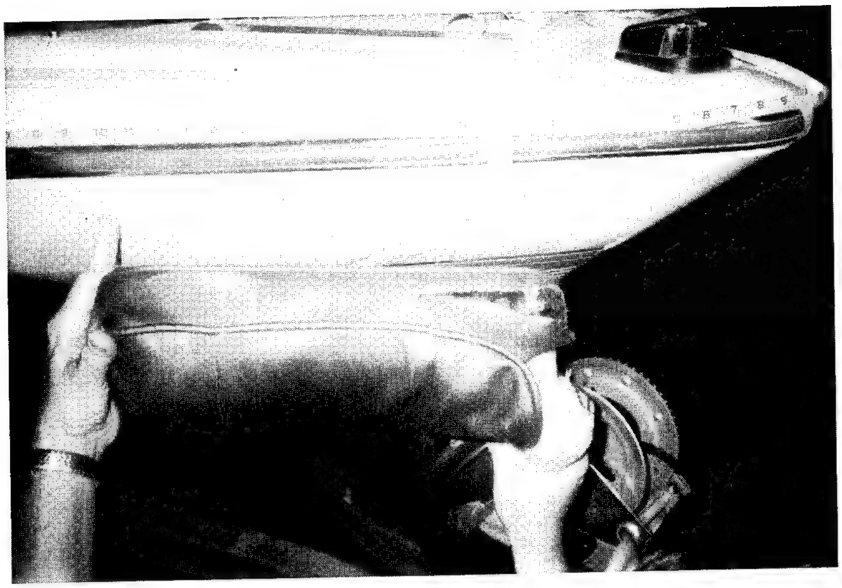


Figure 13-65

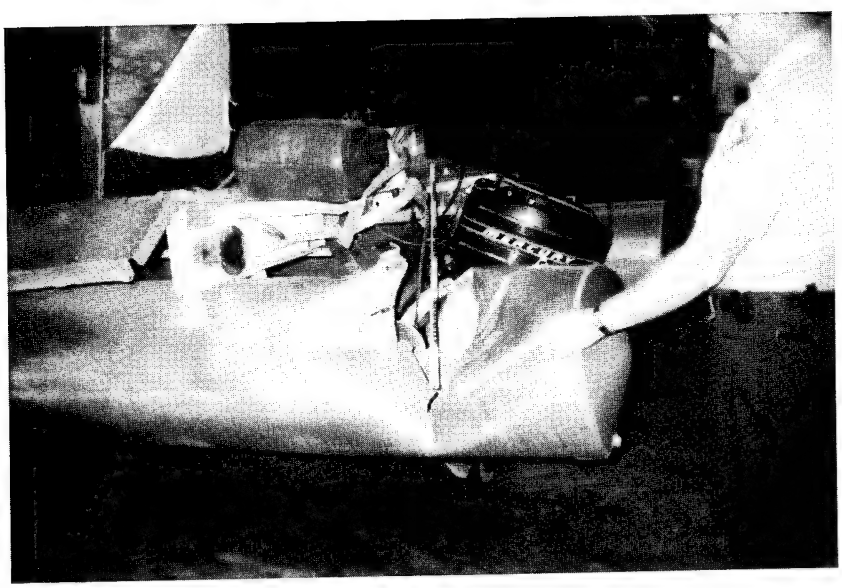


Figure 13-66

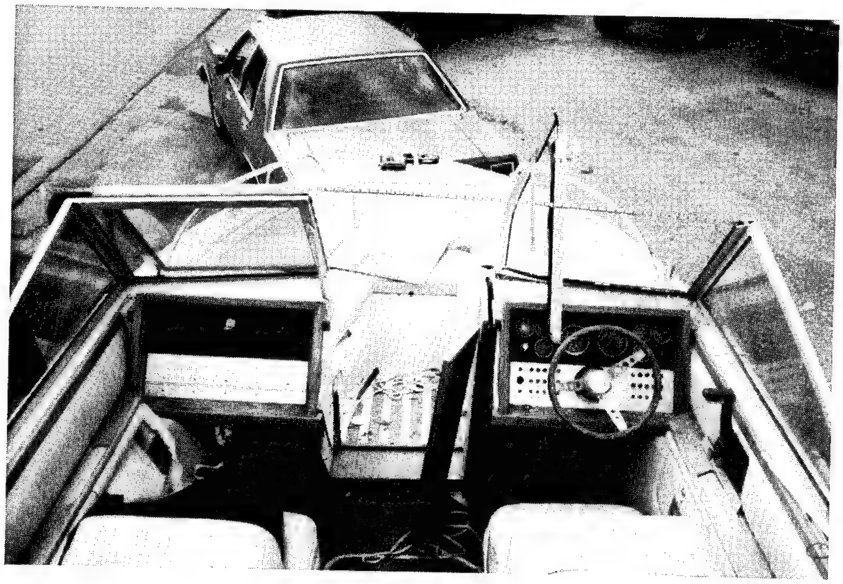


Figure 13-67

Figure 13-68

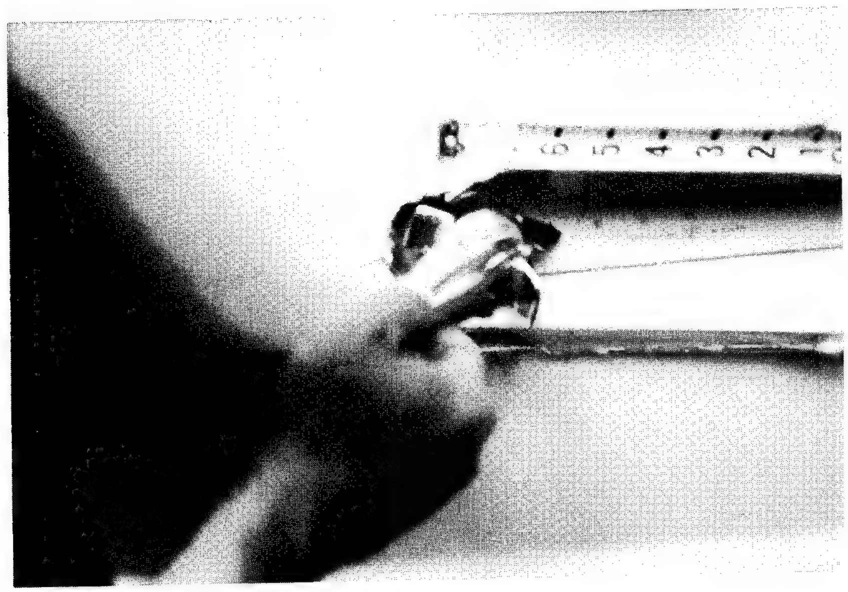
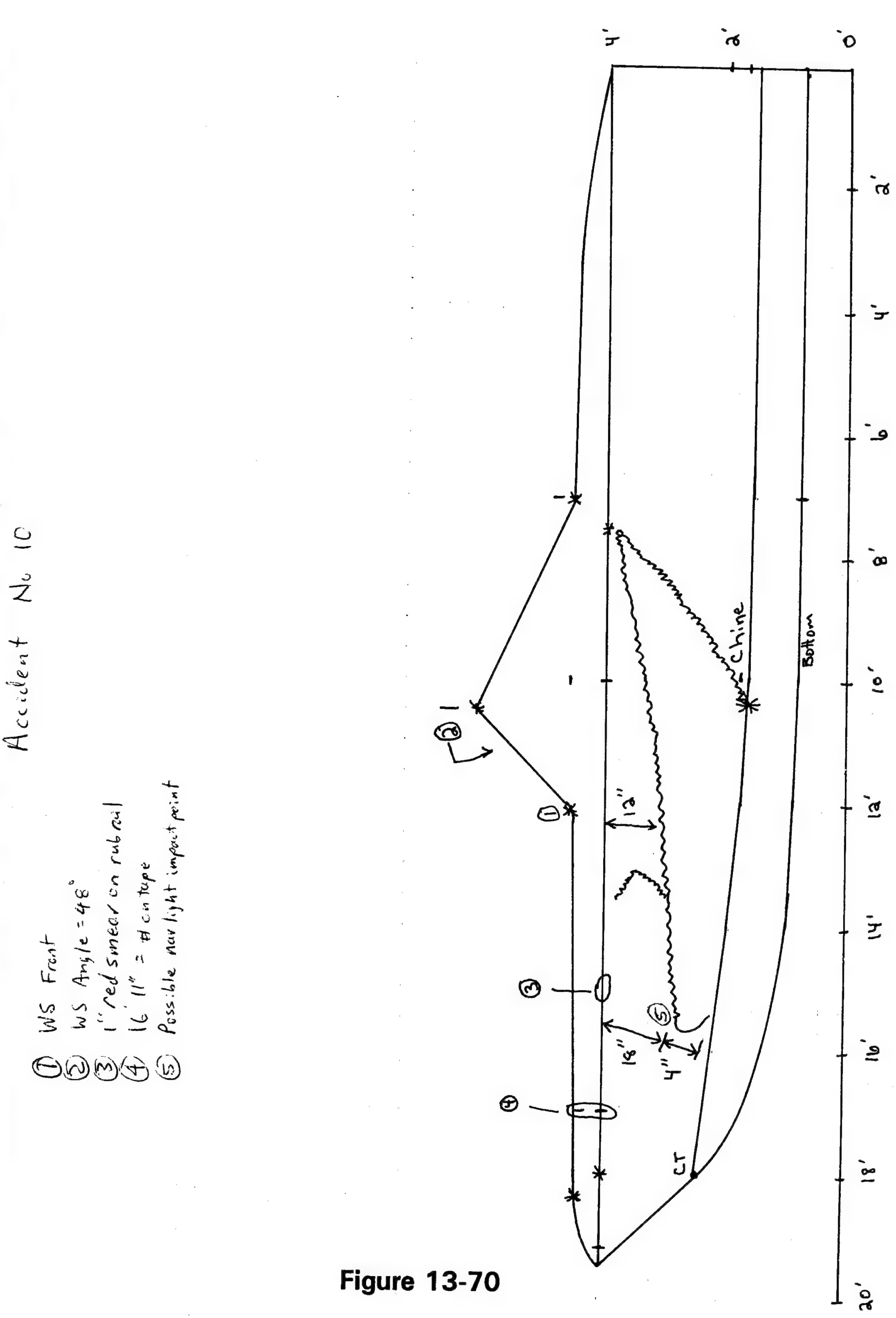


Figure 13-69

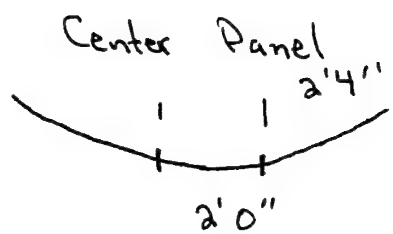


Accident No 10
① WS Front
② WS Angle = 48°
③ 1" red smear on rub rail
④ 16' 11" = # on tape
⑤ Possible nav light impact point
Chine
Bottom
CT
12"
18"
4"
4'
2'
0'
2'
4'
6'
8'
10'
12'
14'
16'
18'
20'

Figure 13-70

Accident No 10

1 end of "hole"
2 hole at chine - aft
3 beginning of hole at chine - fwd
4 Crack
5 Main crackline
6 vertical cut
7 red paint transfer on rub rail



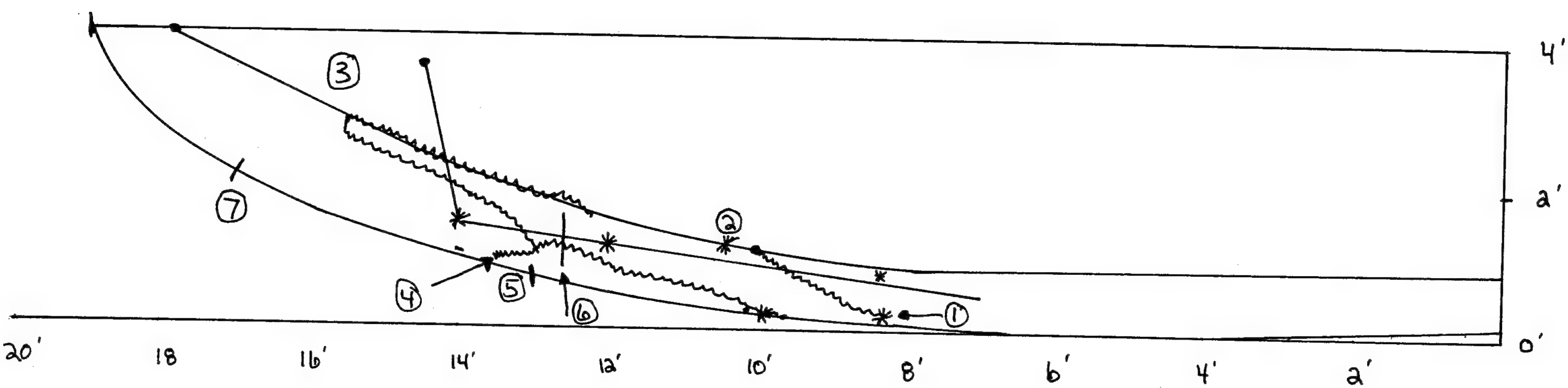
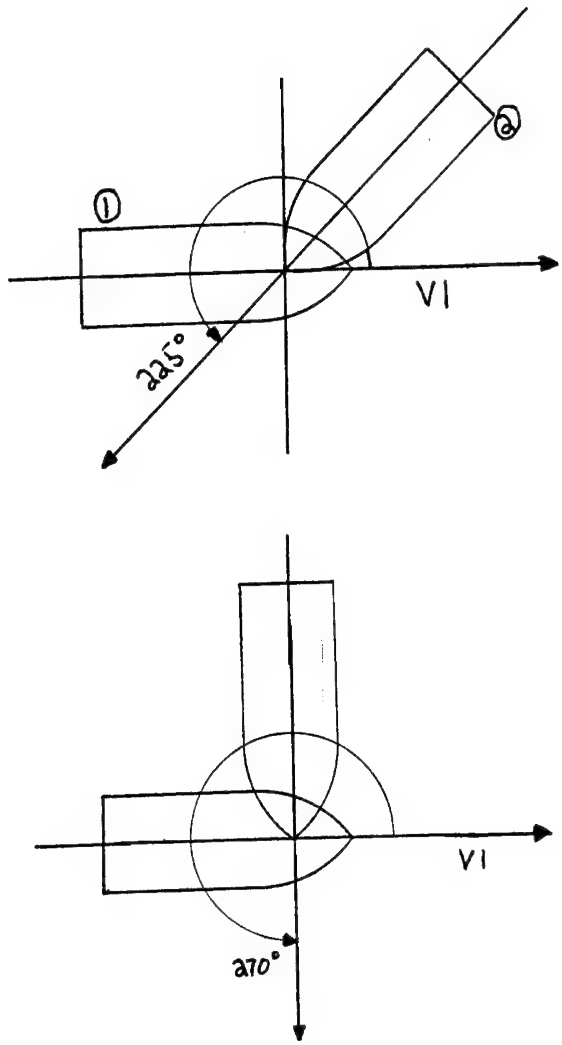


Figure 13-71

Accident No. 10



Possible Impact Angle for Accident No. 10. The Vector Impact Angles Range From Approximately 225° to 270°.

Figure 13-72

CHAPTER 14

COMPUTER SIMULATION OF A RECREATIONAL BOATING COLLISION ACCIDENT

14.0 Introduction

Accident reconstruction techniques in the boating area are not as advanced as reconstruction techniques in other areas of transportation. The state of the art in the automobile and aircraft areas with regards to accident reconstruction may involve extremely sophisticated computer programs running on supercomputers. Common methods applied by accident reconstructionist may involve a detailed analysis at the scene, laboratory testing on failed parts, careful examination of the damaged structures, and the use of microcomputers and special software to verify hypotheses.

In most states however, the current level of boat collision accident investigation and reconstruction is somewhat less sophisticated. A complete investigation may simply be to have an investigator fill out a form which shows the operator's name and address and basic information about the boat! With some minor accidents this may be all that is necessary. The problem is that severe accidents involving multiple fatalities or other serious safety concerns are often not investigated any more thoroughly. Because sophisticated accident reconstruction tools and training in the boating field are generally not well developed, a more thorough analysis is not feasible, at least not for collision type accidents.

The current level of boating collision accident reconstruction is about 20 years behind that of automobile accident reconstruction. This need not be the case. The boating community can take advantage of recent technological developments to catch up quickly. Perhaps the most powerful tool to assist with that task is the computer. One of the goals of this project was to determine the feasibility of applying computers to boat collision accident reconstruction.

14.1 Scope

The scope of this portion of the research was to conduct a computer simulation of a two-boat collision scenario. The simulation was to be as generically representative as possible of a collision accident involving recreational boats. Wherever feasible, the simulation was to include the dynamic forces and characteristics of an actual collision. The primary focus of this simulation was to study the overall collision dynamics. It was not intended as a detailed study of boat structures.

14.2 Why Conduct a Computer Simulation?

There are several key advantages to using computers. First, a computer can quickly conduct literally millions of complex calculations with perfect accuracy that would otherwise not be possible. This allows one to formulate and modify theories and equations at will, and then run the program to evaluate results only moments later.

Second, in order to conduct a computer simulation, virtually every detail of the problem must at least be considered. Computers only execute the instructions provided, and as a result force the engineer and programmer to carefully consider all aspects of the problem in detail.

The collision between two recreational boats is an extremely complex occurrence. Earlier research provided some insight into these complexities, at least in a general sense. Additional information was still needed to develop better accident reconstruction techniques.

The best way to fill in the gaps in our knowledge base would have been to conduct a series of experimental collisions using instrumented boats under carefully controlled conditions. Costs and practical limitations kept this from being a realistic alternative under this project. A secondary alternative was to utilize the power of computers to help formulate theories and algorithms of impact. The results could be studied and modifications made until the results compared favorably with previous experimental collisions. While it may sound a little like cheating, the technique of reverse engineering a simulation is a valid method for developing approximate values for various parameters. Videotapes of earlier experimental collisions provided subjective data on collision trends. This data was used for comparison to the output of the computer simulations to see if the resulting motions appeared to be realistic.

14.3 Specific Purposes

The following specific purposes and goals were set:

1. To simulate a common two boat collision accident scenario;

2. To formulate algorithms of impact that can be used to approximate the response of the boats in the collision scenario;

3. To identify potential strengths and weaknesses of the use of computer simulation in boat collision accident reconstruction and/or prediction;

4. To identify methods to relate impact damage to the accident scenario;

5. To evaluate the potential of using computers to explore the minimum speed threshold theory.

14.4 The Software Used for the Simulation

One of the problems with certain simulation programs is the form of their output. Computer programs are capable of generating mass quantities of tables, graphs, equations, and numbers. So much so in fact, that one often needs a computer to interpret the results! Human brains are accustomed to understanding visual images, not graphs and numbers. The best simulation programs can present their output as visual images. The motion of these images is presented on the screen to show the movement of the actual objects. It was essential that we adopt an approach which allowed the results to be presented visually on the computer screen.

Two software packages were employed for this analysis. The first was used to perform the calculations that drive the simulation. The second was a software package used to interpret and display the results of the simulation in a form easily understood. We will look more closely at each one of these software packages.

14.4.1 Software for Dynamic Analysis

Tremendous research went into locating the software package that was right for the job. The use of computers in other accident reconstruction areas was studied and well understood. The direct applicability of the software and the techniques used in automobile and aircraft accidents was limited. The most popular automobile collision analysis programs treated accidents as two dimensional problems, and thus were not suited for use in a boat collision simulation. A few programs that had the capability to perform analyses in three dimensions were intended only for a certain class of accidents, such as rollover accidents involving heavy trucks or analysis of occupant response to a certain crash impulse. The latter types of programs are used widely in both aircraft and automobile accident analyses to address issues of occupant protection.

What was needed was a software program capable of performing a generalized, three-dimensional dynamic analysis on a multi-body system. Currently, there are not many software packages available that can perform these tasks well. The software chosen for this task was the ADAMS software package. ADAMS (version 5.21) is an acronym for Automated Dynamic Analysis of Mechanical Systems. ADAMS is the most widely used software of its kind. Simply stated, ADAMS is a generalized three dimensional dynamic analysis software package. It is capable of analyzing non-linear systems consisting of

multiple bodies. Popular applications of ADAMS include the simulation of automobile suspensions, various machine and mechanical parts, engines, heavy equipment accidents, and even pilot ejections from military aircraft.

14.4.2 Software Used for the Presentation of the Results

Within the ADAMS software is the capability to present the output graphically. Objects can be represented on the screen and be driven by the simulation to produce an animated effect. These capabilities probably would have proven adequate for our purposes, but the company chosen to perform the dynamic analysis had also developed their own version of an even more sophisticated graphic display software program, called SDI Animator. SDI Animator can be used to create full color realistic images of the modeled objects. The movement of these objects can be viewed real time on the computer screen, providing a quick understanding of the dynamics involved in a complex series of actions. For example, it would take hours of study to examine a series of charts and graphs of accelerations, velocities, and position time histories to even begin to understand the dynamics of a bullet boat involved in a collision. Using SDI Animator (version 1.0), the results can be viewed real-time, using realistically detailed images. This provides an almost instant understanding of what happened. Just watching the simulation on the computer screen provides a casual observer with about the same information as a person watching the actual collision event.

14.5 The Collision Simulation Team

The knowledge and expertise required to simulate a small boat collision accident covers a wide expanse of areas. It took a special blend of talents to develop and complete the project successfully. After careful research and study, it was determined that we needed the best experts in several areas.

First, we needed an expert familiar with the state of the art in computer simulation. It was necessary to have someone with knowledge of the capabilities of a wide variety of software and hardware in this area. This person would help to select the software, the hardware, and the company or individuals best suited to perform the actual simulation. This individual would also play a key role in keeping the project on track once initiated.

The person selected for this role was Dr. Milton Chace. Dr. Chace is a pioneer in the development of the computer-aided engineering field of large displacement, multi-body, mechanical dynamic system analysis. This is exactly the type of software needed to perform the simulation. Dr. Chace was heavily involved with the early development of the ADAMS program. In addition, he is also knowledgeable about other programs in its class.

Next, we needed a uniquely qualified and experienced group or company to actually perform the simulation. This company was required to have experience conducting complex simulations in a variety of areas. We needed a creative, aggressive group unafraid to tackle new areas. It was also deemed necessary to locate someone with interest and experience in small boat design and analysis.

Extensive research was conducted to locate those companies with the experience and expertise required. Simulation Dynamics, Inc. (SDI), with President Mark Rupersburg at the helm, was chosen to execute the simulation. SDI has extensive experience using ADAMS to conduct simulations in an impressive variety of complex situations. SDI also offered the additional benefit of providing access to a superb graphics program to assist with the interpretation of the results. SDI was accustomed to generating high quality images during a simulation and transferring them to standard VHS videotape for easy viewing.

The final area requiring expertise was small boats and hydrodynamics. The hydrodynamics involved in the simulation of a boating accident are highly complex and a critical part of determining each boat's response. Proper input into the simulation in this area was of paramount importance. Once again, it was deemed ideal to locate someone familiar with boating accidents and the complexities of the small boat world. Once again, after a long search, the ideal expert was located. Frederick Ashcroft, a research engineer at the University of Michigan, was chosen. Ashcroft is a naval architect, experienced researcher, and intimately familiar with small boat design concepts. He has spent considerable time studying and testifying as an expert in small boat collision accidents. Thus, he was not only interested in our research, but was uniquely qualified to fill in the necessary gaps.

You should note that there is not an expert in boat structures, composite materials, or other related areas listed above. Research conducted early in the project lead to the conclusion that the general dynamics that occurred in small boat accidents were more important to understand than the details of the structural problem, at least in the early stages of development. For this simulation, it was decided not to pursue any in-depth analysis of the structural deformation of the boat hull on the computer. A detailed study of the structural response would have required data that was not readily available, and more importantly, an entirely different approach. When specific structures are analyzed, the problem becomes more focused on a particular material or boat structure, thus lessening the impact of the program as a generic model.

14.6 Selecting a Collision Scenario

The scenario selected involved a relatively common accident situation where one boat is sitting motionless in the water, and a second boat strikes it at a right angle from the side. Six different runs were conducted, each at different speeds. Impacts were simulated with the bullet boat traveling at 5, 10, 15, 20, 25, and 30 mph. The boats utilized would be small open motorboats representative of a common design.

The dynamics involved in an impact vary greatly with speed. One of the purposes of conducting the impacts at various speeds, was to see how well the various modes of impact could be modeled.

The reasons for selecting this scenario are outlined below:

1. Choosing a scenario with both boats moving was not considered since it is the most complex type of accident. Also, there was not any data on a real collision available with which to compare the results.

2. Several staged collisions had been conducted earlier by UL that matched this scenario. This would permit at least subjective comparisons of the computer model to a real collision.

3. UL had conducted collisions in this scenario at approximately 5, 10, 15, 25 and 30 mph, though not all with the same pair of boats. Originally, consideration was given to conducting runs at 40 and 50 mph, however it was decided not to conduct runs at those speeds for several reasons. One was that UL had not conducted collisions above 30 mph, and secondly the design parameters of the boat modeled limited it to a real life speed of 30 mph.

14.6.1 Selecting an Impact Point

Considerable discussion went into determining the best impact point on the target boat. Originally, the intent was to have the impact point forward of the CG and CLR on the target boat so that it would rotate during impact. To model the hull rotation accurately required in-depth knowledge of the hydrodynamic forces on the hull and the initial hull response upon impact. Unfortunately, sufficient data was not available to permit this type of detail in the simulation. It therefore became a necessary simplification to align the impact point with the center of rotation (CR) so that no hull rotation occurred. This was not all bad as it helped the simulation team to focus their attention on

developing strong impact algorithms and on hydrodynamic effects. Since this was the first time a simulation of this nature had been attempted, it was agreed that it was better to keep it simple and do a good job, rather than complicate it so much that it became an impossible task! The target boat was permitted to roll and pitch during impact as the collision progressed.

14.6.2 Degrees of Freedom (DOF)

The ideal simulation would model all six DOF for both boats. For the purposes of this feasibility study, the bullet boat was restricted to three DOF. The bullet boat was not allowed to move laterally, roll about its longitudinal axis, or yaw about its vertical axis. These restrictions simplified the coding required for the simulation without significantly affecting its accuracy. Thus, the bullet boat was free to rotate about its pitch axis, and translate in the vertical and horizontal directions. The target boat was modeled using all six DOF.

14.6.3 The Boats

The goal was to model a typical motorboat in the 16 to 19 foot length range. The boat was to have a hull form typical of a large percentage of modern craft. In the interest of economy, the same boat design was used for both the bullet boat and the target boat.

Instead of choosing a hull form which belongs to a particular manufacturer, we chose to create a generic planing hull form representative of a large number of modern watercraft. This hull form was designed by Ashcroft and is shown in Figure 14-1 and Figure 14-2.

The hull was designed to be typical of a planing boat with average performance. Characteristic properties of high performance or special purpose hulls were deliberately avoided. The intent was to make the boat as generically representative as possible. The boat was modeled with a 90 HP outboard motor. The transom of the hull was designed with the standard 14 degree transom angle.

Once the boat was designed, it was assigned a weight and mass properties. The mass properties were necessary for the ADAMS simulation so that appropriate reaction and inertial forces could be generated. The mass properties of the boat were also necessary in order to generate realistic trim angles and attitudes for the boat in the water at varying speeds.

Both boats had weight, mass and associated inertial values. The effects of gravity were included on both boats.

14.7 Method

14.7.1 Summary of Steps Required

A summary of the steps taken to research and execute the simulation are summarized below.

1. Evaluate the benefits and current application of computers in the automobile and aircraft accident reconstruction and simulation areas

2. Evaluate the potential benefits and feasibility of conducting a recreational boat collision computer simulation

3. Determine the requirements and capabilities of the software needed to conduct the simulation

4. Conduct research to locate software with the necessary requirements

5. Determine the outside expertise required, and locate the best in each area (general computer simulation, small boats and hydrodynamics, and simulation expert)

6. Choose the software needed, and determine its hardware requirements

7. Select the desired collision scenario and determine methods to be used.

8. Conduct a trial run of the simulation using the best data available.

9. Compare to experimental collisions previously conducted for similarities and discrepancies.

10. Refine simulation model based on results of (9) above.

11. Analyze results and write report

14.7.2 General Simulation Layout

The scenario chosen was executed utilizing bullet boat speeds of 5, 10, 15, 20, 25 and 30 mph. The scenario began at a point in time approximately two seconds before impact, and ran until five seconds after impact. For collisions involving a trajectory, the simulation ran for at least one second after the bullet boat re-entered the water.

One of the advantages of using a computer is that virtually any information desired, such as forces, velocities, accelerations, etc., can be obtained at any point in time for any part of the boat desired. The same is true regarding views and perspectives. The event being modeled can be viewed from any position or perspective.

For each simulation run, at least three views of the entire run were recorded and transferred to videotape. Each view was then recorded in real-time, and then in slow motion.

Only video data was provided for all runs except the 30 mph impact. Several experimental collisions had been conducted previously by UL at approximately 30 mph. Since the 30 mph impact was of special interest, additional data was obtained. Both graphs and tabulated data were printed that contained specifics regarding forces, accelerations, positions, and related parameters as a function of time. If instrumented tests are conducted in the future, the data from the instrumented boats can be compared to that presented in this report. This will provide valuable information to refine the simulation model.

14.8 Algorithms and Assumptions

14.8.1 Boat Hull Performance and Characteristics

When developing the algorithms and equations used in the simulation, it was necessary to start with the basics. The basics included determining such information as how the bullet boat would travel through the water and how the hull of the target boat would respond to the impact.

Before any equations could be entered into the ADAMS program, the properties of the boats utilized had to be fully developed and understood. Mass properties, stability characteristics, and performance predictions for speed, trim angle, dynamically supported weight and related parameters were calculated.

This work was conducted by Ashcroft using a variety of techniques. All of the hydrostatic calculations were performed using the Intact Stability Program - INTAC 1.1, Adapted from the Ship Hull Characteristics Program (SHCP), from the University of Michigan, Department of Naval Architecture and Marine Engineering. The data generated from this program can be found in Volume 2 of this report.

The dynamic performance curves generated were based primarily on the data presented in a paper entitled the "Hydrodynamic Design of Planing Hulls," by Daniel Savitsky, published in the October 1964 issue of Marine Technology. This paper is still a standard teaching reference for planing boat design.

Data considered essential for the simulation was generated. A summary of the required types of data are listed below:

1. Trim angle vs. speed;
2. Roll stiffness at zero speed (righting arm);
3. Basic hull properties at each speed;
4. Rise in CG for each speed;
5. The location of the center of pressure.

The types of data listed above were generated and used as inputs to the ADAMS program or used to verify ADAMS calculations as appropriate.

For our model, the assumption was made that all forces would act through the CG of the boat. This helped to make the model as generic as possible. These assumptions were deemed to be reasonable for preliminary design purposes, since no particular hull form was modeled. Allowing the forces to act through the CG also permitted the use of a simplified version of the Savitsky equations (found in reference 4) to predict the planing speed of the hull. This method was checked against hulls used as examples of Savitsky's work and the Series 62 paper (reference 5) and found accurate within a few percent for boats ranging from 3,000 to 100,000 pounds displacement. A brief synopsis of the methods used to calculate each parameter listed above, as well as why that data were important is discussed in the following sections.

1. <u>Trim Angle vs. Speed</u>

The graph of trim angle vs. speed found in Figure 14-3 was generated using the simplified Savitsky equations. These data place the bullet boat at the proper trim angle at impact for the various impact speeds used.

2. <u>Roll Stiffness at Zero Speed</u>

Roll stiffness, also referred to as righting arm, was obtained from the Static Stability Curve found in Figure 14-4. Four curves are shown on this plot. Each one assumes a different coordinate for the Vertical Center of Gravity (VCG). The values used ranged from 0.0 to 3.0 ft. The VCG value of 2.0 feet, labeled as Case 3, was used for our model. The Longitudinal Center of Gravity (LCG) is shown on the graph as minus 2.511 feet. This means that for this graph, the LCG was located 2.511 feet aft of amidships.

The static stability curves are necessary to determine the proper roll response of the target boat when struck from the side. The computer generates information regarding the forces and their locations applied to the hull of the target boat during impact. These forces translate into moments about the CG of the target boat that have the tendency to roll the boat. The roll stability data determines the proper roll angle for a given moment. The static stability data was generated using INTAC 1.1, Adapted from the Ship Hull Characteristics Program (reference 3).

3. Basic Hull Properties at Each Speed

Basic hull properties such as station sectional areas and hull form coefficients (such as waterplane areas and moments of inertia) were calculated for the boat fixed in trim at the match point rim angles from the speed/power calculations. This data was used to verify the dynamic balance calculations used in the ADAMS simulation.

4. Rise in CG at Each Speed

When a boat is at zero speed in the water, its entire weight is supported by the buoyant force created by the displaced water. When a boat is on plane, very little of the hull may be in the water. Although some water is displaced, there is certainly not enough buoyant force to keep the boat afloat. Thus, there must be another force that helps to support the weight of the boat. This force is called the dynamic lift, and is created by the water passing underneath the hull with the boat at the proper trim angle. The amount of the weight supported by this force is called the dynamically supported weight.

The value of the dynamically supported weight is zero when the boat is stationary or at low speeds. When the boat is on plane, most of the boat's weight may be dynamically supported. The value of the dynamically supported weight is important in determining the rise in CG of the bullet boat as it travels from zero to various planing speeds. Proper placement of the CG of both boats at impact is an essential part of creating an accurate simulation.

5. The location of the Center of Pressure

The center of pressure is the point through which the hydrodynamic forces act on the bottom of the hull as the boat moves through the water. For our model, it was assumed to act through the CG.

14.8.2 Driving the Bullet Boat Through the Water

For each simulation run, the bullet boat was simply set at the desired speed. The trim angle was determined using both data generated by Ashcroft, and by the ADAMS program. The hydrodynamic forces acting on the hull were modeled by the ADAMS program. The trim angle calculated by ADAMS was compared to the slightly more accurate values generated by Ashcroft. The slight differences obtained are attributed to a greater accuracy of the SHCP for these purposes. In order to conveniently match these two values, the location of the CG was shifted slightly fore and aft from one run to the next, iterating until the two trim angle predictions matched. For the purposes of this simulation, these differences were determined not to have any significant effect on the results.

14.8.3 Bullet Boat Structure

The bullet boat was modeled as a totally rigid non-deformable structure. This model is representative of a bullet boat's structure that is involved in a collision in most cases. Rarely, even in 30 mph collisions does the structure of the bullet boat suffer badly when striking a fiberglass boat.

14.8.4 Target Boat Structure

The target boat's structural response was a critical part of the simulation. Unfortunately, it is also one of the most complex parts of which few specific details were available. The goal was to develop a relatively simple model of a very complex event. The details of the deformation of a composite laminate boat hull breaking apart during impact could be the focus of an entire research project. The structural response and vessel interaction from several experimental collisions were studied. Instead of modeling in detail the structural deformations of the target boat, mechanical representations of large scale deformations were used. The focus was on developing reasonable force vs. deflection curves instead of modeling material stresses and strains.

The scenario was set up so that the target boat was impacted at the CR (Center of Rotation) so that no yawing would occur. Furthermore, it was assumed that the center of gravity (CG), center of rotation (CR), and center of lateral resistance (CLR), were all co-incident at one point, and that this point was in line with the impact point. The boat hull was modeled as a rigid body except in the areas immediately involved in the impact. No allowances were made for overall large scale structural deflections or distortions of the hull. In other words, the overall hull shape was not permitted to bend or twist.

14.8.5 Structure To Determine Initial Impact Response

During an impact, fiberglass hull sides can flex over a relatively large distance without breaking or without penetration occurring. When the load reaches some critical point, the hull will fracture and separate as the bow of the bullet boat begins to penetrate. This set of conditions was modeled by determining a maximum breaking force for the hull side (set at 5000 lbs), a force deflection curve (8500 lb/ft), and a maximum linear viscosity coefficient (set as 10 (lbf-sec)/ft). The latter term determines a resistant force applied contrary to the impending motion of the bullet boat proportional to the relative speed of the two vessels.

Unfortunately, there was not sufficient hull structural data located to base all of these parameters on experimental data. Most of these numbers were based on trial and error and engineering judgment. The basic relationships were understood; however, the specifics of all the values for various parameters were not known. The simulated collisions as viewed in SDI Animator were compared to videotapes of similar collisions. Differences in reactions and dynamics were observed. Often it was necessary to go back into the model and refine certain values until the video outputs corresponded more closely.

Since the simulation differed from any particular experimental collision conducted, it was not expected that the response of the model would or should precisely match the response of a previous experiment. Therefore, some of the differences were understandable and realistic, given the differences between the model and the actual event.

14.8.6 Structure to Determine Mid and Late Impact Response

Even though much of the hull material on the struck side is damaged or swept away, the dynamics of the collision are largely determined by two hard points on the vessel. Choosing the proper location of these hard points was critical to the success of the collision. The diagram in Figure 14-5 illustrates this point. Points 1 and 2 represent the locations chosen for these hardpoints.

Point 2 is the top of the gunwale on the side opposite of impact. Damage at this point in many collision accidents is either minimal or non-existent. The boat either completely clears this gunwale, or slides across the top of it as the collision progresses.

Point 1 is a location that is more variable, and does depend on the structure of the target boat hull side, and the geometry of the bullet boat. For our model, the location of this hardpoint is the intersection of the hull and chine. For a target boat with relatively soft hull sides, this is a good location.

When discussing these impact hardpoints, it is important to realize that these may not be hard points as thought of in the traditional sense. A hard point is usually thought of as some reinforced portion of the boat or a point where the structure is deliberately made rigid and stiff, such as at a bulkhead location. An impact hard point as defined in the simulation is defined as a location about which most of the weight and corresponding impact forces of the bullet boat seem to be concentrated. These are locations which likely support most of the boat's weight, or provided a large resistance to an impact, and thus determine the response of the striking boat. These locations, with regard to collisions, may be more appropriately called support points. In some collisions, these points are not clearly defined or may exist for only a portion of the collision.

14.8.7 Friction During Contact

Friction during the impact was grossly simulated by applying a constant value friction force of 468 lbs while the two vessels were in contact. This corresponds to a dynamic coefficient of friction of 0.1 when normal forces are equal to the bullet boat's weight. This approach was used to simplify the coding involved. A true friction simulation would have involved applying a variable linear friction force that varied as a function of the normal contact forces.

14.8.8 The Simulation of Impact as Conducted by ADAMS

The simulation consisted of three main objects defined as parts. Part 1 was defined as the global origin. Part 2 was the bullet boat, and Part 3 was defined as the target boat. Each part has associated with it a Local Part Reference Frame (LPRF). The LPRF is a triad of unit vectors which is attached to and moves with the part.

To understand how ADAMS was used to simulate the impact, it is necessary to have a clear view of the marker geometry which is used in the impact force computations. A marker is simply a reference point in the simulation that is of some special interest to the programmer. To the computer, a marker is the combination of a point and a triad of unit vectors, thereby providing both position and orientation. Each marker is given a number simply to provide a means of identifying it. The number is in no way associated with the coordinates (location) of the marker. For example, marker 100 does not mean that the marker is located at a position 100 units away from the origin.

All geometry used for the impact analysis is represented with respect to the LPRFs. The LPRF acts as the sole reference for defining any collection of markers that move with the part. These LPRFs need not be located within the physical boundaries of their respective parts, as might be expected. Instead, they can be located well outside of the boundaries of the part with which they are associated.

Figure 14-6 shows the overall geometry of the collision scene at the beginning of the simulation run. Five important markers are included in this figure. Marker number 100 is a fixed reference point, located on the surface of the water in line with the path of the bullet boat. This point serves as the global origin for the simulation. Markers 200 and 201 are fixed relative to part number 2 (the bullet boat). Markers 300 and 301 are fixed relative to part number 3 (the target boat). Markers 200 and 300 are identified in the respective part 2 and part 3 statements as center of mass markers. Markers 201 and 301 are positioned directly under the bow points of the boats, on the extension of the keel lines, as shown in Figure 14-5.

In the beginning of the simulation run, at time zero, each part and its associated LPRF are placed in the proper location on the global coordinate system with respect to marker 100. Remember that marker 100 is the origin for the global coordinate system. Note that the x local coordinates of markers 200 and 201 are large numbers when entered in the data, 132.850 and 120.000 respectively. Likewise, the impact center markers also have correspondingly large x values.

In Figure 14-6, the directions associated with the markers are shown as right-handed triads of unit vectors. Small circles with dots in the center indicate unit vectors directed out of the plane and small circles with crosses indicate unit vectors directed into the plane. Note that markers 300 and 301 have been rotated 90 degrees about their z axis, relative to the initial orientation of the part 3 LPRF. Placing these LPRFs in this orientation halves the problem of defining hull geometry for graphics purposes. The hull coordinates of the bullet boat relative to marker 201 are identical to the hull coordinates of the target boat relative to marker 301 as rotated.

Figure 14-5 and 14-7 show the essential marker geometry used on the bullet and target boats to set up the impact computations. The keel and bow of the bullet boat are represented by a series of 19 two-foot diameter circles. The centers of these circles are located at markers 20001 through 200019. On the target boat, points of possible collision are represented by markers 3200 (port gunwale), 3300 (starboard gunwale), and 3400 (port chine).

Thus, there are 57 (19 x 3) possible force fields defined between all possible combinations of one of the target boat markers, and the 19 circles on the bullet boat. Throughout the numerical integration of system motion, ADAMS constantly checks to see if any of the 19 circles has made contact with or penetrated the three target boat markers. If penetration has not occurred, the

contact force is set to zero. If penetration has occurred, a special predefined IMPACT subroutine in ADAMS is called. This routine computes a repulsive force which increases steeply with increasing penetration. For forces involving markers 3300 and 3400 the force can increase indefinitely. This simulates impacting, sliding, or bouncing across the starboard gunwale or the port chine. For forces involving marker 3200, the repulsive force can increase to a maximum value of 5000 lbs. If the 5000 lbs force is reached, the repulsive force is decreased to zero. This simulates breaking through the hull side.

As discussed earlier, this representation of impact included both a force-deflection characteristic, which was set as a linear function of 8500 lb/ft. It also included a damping effect, rising to a maximum linear viscosity coefficient set as 10 (lb-sec)/ft.

14.9 Presentation of Data

14.9.1 Overall

The graphics created by SDI Animator based on the ADAMS computations were transferred to standard VHS videotape for easy viewing for all simulation runs. Additional data was generated for the 30 mph collision. Both graphs and tabulated data of various parameters were generated. A list of the graphs generated can be found in Figure 14-8. All graphs and tabulated data may be found in the Appendix, Volume 2 of this report.

14.9.2 Graphics

The graphics of each simulation run provided valuable information with regard to boat responses. The boats used in the simulation were identical hull forms but were colored differently to enhance the quality of the graphics. Both boats were shown with windshields and outboard motors, however these objects were used in appearance only, and not assigned any structural characteristics.

An initial problem with analyzing the output of the graphics was trying to establish a point of reference. The boats traveled at different speeds for each run. However when displayed on a solid color background (the water), no visual cues were present to provide a feel for speed. Consequently, a light colored grid was placed on the water's surface to assist with visual interpretation of the events displayed.

14.10 Results

The only data output for all collision runs except the 30 mph impact was the video data. Both tabulated and graphical data in addition to the video data were generated for the 30 mph impact.

Figure 14-8 contains a list of all graphs data generated for this collision. All of the graphs and data for the 30 mph collision are contained in Volume 2, Appendix.

14.10.1 Overview

This section will present an overview of the collisions conducted from 5 to 30 mph based on the data provided on the simulation videotape. The following description of events is based on the graphics presented for each simulation run.

Impacts were conducted at 5, 10, 15, 20, 25, and 30 mph. We will briefly describe significant motions of the target boat and the bullet boat. Also, an assessment of the accuracy of each run will be made.

14.10.2 Impact - 5 MPH

The bow of the bullet boat was observed to rise slightly at impact. Its motion basically stopped and its energy transferred to the target boat. The target boat reacted quickly and slid approximately seven feet laterally through the water before stopping. The target boat did not roll about its longitudinal axis at impact. There was no penetration of the hull side of the target boat, indicating that the peak impact forces were less than 5000 lbs. The actions and reactions appeared to be relatively accurate for this speed.

14.10.3 Impact - 10 MPH

The bow of the bullet boat pitched up at impact noticeably, then penetrated the hull of the target boat. The bullet boat then continued to climb up over the target boat until its bow was hanging over the far side of the target boat. The lower portion of the bow was actually resting on the rigid gunwale. At that point, the velocity of the bullet boat relative to the target boat was zero.

The target boat experienced a series of changes in roll angle as the impact progressed. Initially at impact, the target boat rolled slightly toward the bullet boat, then leveled off as penetration began. As the bullet boat penetrated further, the target boat began to roll in the opposite direction. Once contact was made, both boats slid through the water together for a distance of approximately 9 feet.

The roll motion of the target boat is considered to be reasonably accurate for this type of engagement. At this speed, the hull side appears to be too soft, as 10 mph impacts do not generally lead to hull penetration. Since penetration occurred, it is an indication that the impact forces exceeded 5000 lbs.

This collision involved a fairly extensive override. The bullet boat stopped on top of the target boat. There was relatively little decrease in velocity once penetration occurred. This is a possible indication that the friction forces modeled are not high enough.

What appeared to be missing from this model was a component of a reaction force that acts vertically upward on the hull of the bullet boat after it has penetrated the hull side. The bow of the bullet boat started to rise as it struck the hull side, but immediately dipped back down once penetration had occurred. In a real collision, this does not generally occur. While it may be true that the restraining forces which prevent the boat from driving forward are reduced after the bow has broken through the hull side, the vertical forces which act on the bottom of the hull change more gradually. This force is believed to be a function of the hull side stiffness, and the shape of the bow of the bullet boat. It may be possible to write a more accurate function in future simulations to take these forces into account.

14.10.4 Impact - 15 MPH

The general motion was almost exactly as described for the 10 mph collision with only a few exceptions. There was no visible change in roll angle of the target boat or in pitch angle of the bullet boat at impact. This suggest that the impulse created at impact was of such a short time duration that the boats did not have time to react. The bullet boat rode up onto the target boat further than at 10 mph. The bullet boat's motion relative to the target boat stopped when the bullet boat's outboard was within 1 to 2 ft of the side of the target boat. The bullet boat did not ride all the way over the target boat. After first contact, the two boats slid together through the water approximately 13 feet.

The accuracy of the model is difficult to assess in this case because so few controlled collisions have been conducted at this speed. The basic motion of both boats appears reasonably accurate. The trim angle of the bullet boat appears lower than would be present for a small boat traveling at "hump" speed. The question of whether penetration should occur at this speed is not easily answered. It could depending upon the individual structure and geometry of the boats involved.

The basic motion of this impact is very similar to one experimental collision conducted at approximately 15 mph. For that collision, a 19 foot boat ran over a smaller 14 foot open motorboat. The 19 foot boat stopped on top of the 14 foot boat, which subsequently began to fill with water and sink. For that collision however, penetration of the side did not occur because the bow was well above the side at initial contact.

14.10.5 Impact - 20 MPH

This collision was significant because it was the lowest speed at which the bullet boat actually went all the way across the target boat. There was almost no perceptible free flight trajectory motion associated with this collision. The bullet boat penetrated the hull side immediately with no noticeable reaction from the target boat. The bullet boat then began to ride up onto the target boat, and had just enough energy to slide all the way across it, and re-enter the water.

It is interesting to note that while the two boats were in contact, the target boat slid laterally approximately 12 feet. As the bullet boat began to leave the target boat, the target boat rolled steeply in the direction away from the impacted side.

The general motion and trends represented by this impact appear to be fairly accurate. This impact suggests that this is about the lowest speed at which it is likely for the bullet boat to travel all the way across the target boat. For the boats modeled here, this appears to be a reasonable result. Caution in assessing the accuracy of this model is needed due to the limited amount of data available for comparison which corresponds to this scenario.

14.10.6 Impact - 25 MPH

The general motion of both boats at 25 mph is similar to that described for the 20 mph collision with only a few exceptions. The bullet boat struck and traveled over the target boat more easily. The target boat slid laterally only about 5 feet while the two boats were in contact. There was no perceptible reaction from either boat when hull penetration occurred. The bullet boat did not experience any significant trajectory motion. The bullet boat appeared to have traveled approximately 5 feet horizontally through the air after last contact with the target boat.

The lack of any perceptible reaction when penetration occurs is a reasonable response. This is consistent with collisions conducted on fiberglass boats of approximately this size in past experimental collisions. Typically, by the time the bullet boat speed reaches 25 mph, there is a significant height and distance to the trajectory of the bullet boat.

14.10.7 Impact - 30 MPH

This was the highest speed impact simulated. Simulations were not conducted using higher target boat speeds for one primary reason. No experimental collisions had been conducted at speeds greater than 30 MPH so that the data could not be compared to a real event.

The dynamic response of both boats at this speed is representative in many ways to previously conducted experimental collisions. The bullet boat penetrates the hull side without any perceptible response from the target boat. The target boat does not respond by either pitching or rolling until the bow of the bullet boat makes contact with the far gunwale. This is consistent with previously conducted experimental collisions. The bullet boat then travels across the target boat and leaves airborne. In the simulation, the bullet boat achieves a low height free flight trajectory motion for approximately 15 feet horizontally after last contact. The target boat rolls slightly inward toward the bullet boat after the bullet boat penetrated the hull side. The target boat's roll position then changes rapidly as the collision progresses. It goes from leaning in toward the collision to leaning away from the collision. At last contact, the roll angle of the target boat is approximately 45 degrees.

At the point when the outdrive penetrates the hull side, the target boat is rolled so far that the chine on the initially impacted side is completely out of the water. This suggests that the lower unit and propeller of the bullet boat may be completely out of the water when it penetrates the hull side. Again, this is consistent with some of the previous data collected. The size and geometry of the hulls involved play too large a role in the collision, so we cannot assume that this is generally what happens.

The severe change in roll attitude of the target boat is representative of what happens when striking a boat with a high CG or a with a high structural density. It is also representative of a collision in which the impact force is directed well above the CG on a boat with low roll stability. In our model, the severe roll of the target boat is largely caused by modeling the far gunwale as a rigid body. The target boat rolls with a sudden jolt when the bow of the bullet boat strikes the gunwale. The resulting motion of the bow of the bullet boat as it clears the gunwale of the target boat is abrupt. The change in pitch and the elevation of the target boat in an actual collision is generally a smoother motion. In the experimental collisions conducted, the bullet boat is generally at a greater trim angle and possibly more elevated at the point when the lower bow reaches the far gunwale. This means that the motion of the bullet boat's bow as it clears the gunwale of the target boat is much smoother than what the simulation showed.

One major difference between this impact and previous experimental collisions is the resulting trajectory motion. In the actual collisions, the bullet boat may travel 30 to 40 feet horizontally in the air after last contact. Trajectory motion in the simulation is much more limited. The differences could be due to a variety of variables. The boats in the simulation were not intended to simulate any actual boats, thus the mass properties of the boats used are probably different than those involved in the actual collisions. The boats used in the collision are heavier than the actual boats used in some of the past studies. The heavier the boats, the more substantial the hull side of the target

boat must be so that it does not simply collapse on impact. Thus, the target boat structure must be modeled in such a way as to provide a certain amount of resistance to collapse in the vertical direction. This stiffness creates the necessary ramp effect for the bullet boat to obtain a vertical acceleration. One weakness of our model was a lack of an accurate vertical force component associated with the hull sidewall. This would have helped to impart a greater pitch angle of the bullet boat upon impact and provide a more solid surface from which the bullet boat would be "launched." The pitch moment of inertia of the bullet boat also has much to do with how much vertical reaction force is required on impact to create the proper pitch up transition response.

For the simulation of our target boat, we selected the chine at the plane of impact as one of the rigid points. This hard point represents the bottom of the hull side impacted area, below which no vertical penetration of the hull side by the hull of the bullet boat occurs. Penetration below this point by the skeg and propeller may occur. The location of this hard point is significant because it has a tremendous effect on the resulting dynamics of the bullet boat. Earlier experimental collisions showed that this point may be well above the chine. As the height of this point increases, the chances of the bullet boat clearing the far gunwale generally increase.

14.11 Analysis of Data

A complete set of graphs and tabulated data for the 30 mph impact may be found in the Appendix, Volume 2 of this report. Figure 14-8 contains a list of the graphs generated by ADAMS for the collision simulation.

14.11.1 Explanation of Graphs and Tabulated Data

The titles of the graphs are somewhat unusual due to the automatic generation of titles used by ADAMS. You will first note that no units appear on the graphs. Units used are as follows and are used consistently throughout the data:

Quantity	Units
Time	seconds
Displacement	feet
Velocity	feet per second
Acceleration	feet per second squared
Angular Displacement	radians
Angular Velocity	radians per second
Angular Acceleration	radians per second squared
Force	pounds force

The labels of COL 1,2,3,4,5,or 6 correspond to the respective x, y, z, yaw, pitch, or roll component of the variable involved. For example:

Label	Value
Col 1	x
Col 2	y
Col 3	z
Col 4	yaw
Col 5	pitch
Col 6	roll

For example, a graph labeled Req 3003, Col 3, Target Boat Acceleration shows a plot of the Acceleration of the CG of the target boat in the z axis. Req stands for request number and serves only to identify the request in the ADAMS code requested this particular plot. It is relevant here only because it provides the reference for the number of the plot of the tabulated data found in Volume 2.

14.11.2 Overview of Technical Data

It is useful for analytical purposes to review a few of the more significant plots provided for this collision.

The primary points of interest are:

1. The change in height of the CG of each boat;
2. The change in velocity for each boat and the corresponding change in kinetic energy;
3. The peak accelerations for each boat.

We will look briefly at each of the above values for the 30 mph collision. One potentially useful method for evaluating collisions that may prove useful in the future involves an energy analysis. In conducting this analysis, we try to account for all of the energy that went into a collision, and determine where it went. For example, some of the energy went into damage, some went into trajectory motion of the bullet boat, and some went into moving the target boat through the water, and so forth. The data available from the computer simulation can help us to perform such an analysis on a theoretical collision. The graphs of velocity and acceleration for each boat are shown in Figures 14-9 through 14-15.

14.11.3 Energy Analysis: Change in Velocity and CG Height

The change in height of the CG of the bullet boat is significant because it represents the first key element in analyzing the minimum amount of energy required to accomplish this collision. We are interested primarily in the net change in height of the CG of the bullet boat. The prediction of this change would

be valuable in analyzing and predicting boat dynamics in future collisions. To be able to predict this value, we must also be able to determine the net change in height of the target boat for the corresponding time frame. We will base our analysis on the following data:

	Initial CG Height	Extreme Value CG Height	Change in CG Height
BB:	0.8 ft	3.1 ft	+ 2.3 ft
TB:	0.75 ft	-0.1 ft	- 0.85 ft

where BB = Bullet Boat
TB = Target Boat

The change in height of the target boat is useful for reference purposes. Its value will be dependent upon many variables, but it is partially dependent upon the vertical acceleration and mass of the bullet boat, and by its dynamically supported weight at impact.

Obviously it takes a certain amount of force to push the target boat down in the water 0.85 ft. While it was not done for this model, it is possible to estimate the amount of force required to depress the target boat down into the water. This could be particularly useful in estimating friction forces. Remember that the friction force is equal to the coefficient of friction times the normal force. Knowing the force required to depress the target boat down into the water, and the precise distance down into the water it was displaced, it becomes possible to calculate the normal force to be used in friction estimates. Now all we need is the coefficient of friction, which must be determined experimentally. Refer to Chapter 13, accident number seven, for additional discussion on this subject.

Using calculations for minimum speed as discussed in Chapter 11, based solely on the change in height of the CG, we arrive at a minimum theoretical speed of 8.3 mph as shown:

$$V_{\min} = \sqrt{2gh}$$

$$V_{\min} = \sqrt{(2)(32.2)(2.3)}$$

$$V_{\min} = 12.2\ ft/sec = 8.3\ mph$$

Clearly this speed is well below that of the actual speed. This tells us that only a relatively small amount of energy is required to achieve the change in height of the cg of 2.3 feet for this boat. Since the boat still had significant velocity after the collision and created some damage on the target boat, we know that some energy went into damage and some energy remained in the form of kinetic energy following contact. We would like to know what percentage of the energy expended went into changing the height of the CG of the bullet boat.

Prior to impact, the boat had a total kinetic energy of:

$$KE = 1/2*mV^2$$

$$KE = (1/2)(4868 / 32.2)(44^2)$$

$$KE = 147{,}257 \text{ ft-lbs}$$

We would like to know where the energy goes in a collision. For this collision, we can determine what percentage of the total energy expended went into raising the height of the CG of the bullet boat if we know how much kinetic energy was lost by the bullet boat in the collision. This can be determined by analyzing the change in velocity of the bullet boat which occurred just prior to impact and immediately after separation.

The velocity of the bullet boat changed from 44 ft/sec to 35 ft/sec during contact with the target boat. The total kinetic energy lost during the collision then is:

$$KE_{initial} - KE_{after\ impact} = \text{Change in KE}$$

$$\text{Change in KE} = 1/2m(V_{init}^2 - V^2_{after\ impact})$$

$$= 1/2*(4868/32.2)(44^2 - 35^2)$$

$$= 53{,}745 \text{ ft-lbs}$$

It is interesting to note the percentage of pre-impact kinetic energy lost in the collision process. For this collision, the value is:

$$\%KE\ lost = \frac{Kinetic\ Engergy\ Lost}{Original\ Kinetic\ Energy}$$

$$= \frac{53{,}745\ ft\text{-}lbs}{147{,}257\ ft\text{-}lbs}$$

$$= 36.5\%$$

One theory for predicting a bullet boat speed for a two boat impact is based on energy lost in a collision. For example, it would be useful if we can determine an average percentage of kinetic lost for a particular class of scenarios. For example, if future testing showed that most 90 degree impacts that occur between 25 and 40 mph result in a 35% loss of kinetic energy, it would provide helpful information to the accident reconstructionist.

We now have enough information to look at the percentage of kinetic energy used to account for the change in CG height of the bullet boat. The kinetic energy required to raise the CG of the 4868 lb boat 2.3 ft would only be 11,194 ft-lbs.

$$\begin{aligned} Percent\ KE\ Lost &= \frac{11{,}194\ ft\text{-}lbs}{53{,}745\ ft\text{-}lbs} \\ &= 20.8\% \end{aligned}$$

Thus, of the energy lost in the collision, we can only account for 20.8% of it by analyzing the change in height of the CG of the bullet boat.

14.11.3.1 Change in Velocity of the Target Boat

The target boat accelerated from zero to a maximum total velocity of approximately 9.79 ft/sec. The maximum velocity in the x direction was 7.18 ft/sec. The kinetic energy of the target boat as its maximum velocity was then approximately 7245 ft-lbs.

If we add this value to the 11,194 ft-lbs accounted for by the change in height of the CG, we can now account for 34.3 % of the kinetic energy lost by the target boat.

We can perform a momentum analysis as described using the relationship:

(Sum of momentums before crash)=(Sum of momentums after crash)

We can predict that the maximum velocity which the target boat can attain as a result of the impact (based on the kinetic energy lost from the bullet boat) is approximately 9 ft/sec. This value should be compared to the 7.18 ft/sec which was the velocity only in the x direction to see how much potential velocity was lost by the hydrodynamic resistance component. If these values were representative of a real collision, we would say that the target boat reached a velocity of only 79.8% of the maximum possible value.

14.11.3.2 Other Energy Considerations

The remaining energy in the model went primarily into the following areas:

1. Distortion of the hull side of the target boat
2. Overcoming the lateral hydrodynamic resistance of the target boat
3. Friction

Thus, these three factors would account for approximately 65% of the kinetic energy lost of the target boat.

14.11.4 Acceleration Data for Each Boat

The primary reason for studying collision accidents is in the hopes that someday this data can be used to help make boating safer. The accelerations and durations that the occupants experience during a collision are one of the best indicators available for analyzing the potential for injury. Occupants of the target boat are obviously at risk from direct impact with the bullet boat, and flying debris from their own boat. But what about the occupants of the bullet boat?

Figure 14-12 and 14-13 show the accelerations for the bullet boat in the x and z axis respectively. The units are given in ft/sec^2. Note that the plot for the z axis shows the pre-impact accelerations at approximately zero. Thus the values obtained from the graph for the z axis must have the component of acceleration due to gravity added for our analysis. This must be done since we are really interested in the forces on the occupants, as calculated from F = ma. Thus, components of acceleration for the z axis expressed in feet/per second^2 will have the value of 32.2 added to them. When acceleration is expressed in g's, the force on an object can be calculated by multiplying this number times the weight of the object. If this sounds confusing, think of the force between the person and the boat if the boat were suddenly allowed to accelerate downward at 32.2 ft/sec/sec. The contact force would be zero! However, if the same boat were suddenly accelerated upward at 32.2 ft/sec/sec, the contact force between the occupant the boat would be two times the occupant weight. Thus, a person weighing 150 lbs would exert a force of 300 lbs on the boat.

The figures on the graphs show a maximum acceleration of 125 ft/sec^2 for the x axis, and 133 ft/sec^2 for the z axis. These values correspond to 3.88 g's and 4.13 g's for the x and z axes respectively. Remember that when acceleration due to gravity is taken into account that the acceleration in the z axis is really 5.13g's. These values occurred at slightly different times during the collision process. Had the peaks for each axis occurred simultaneously, the maximum total acceleration at the CG would have been approximately 6.43 g's. As it was the maximum total acceleration was 5.80 g's.

What affect does this have on the occupants? The occupants will experience a force that acts on them opposite to the direction of the acceleration vector and equal in magnitude to their mass times their weight (F= ma). Figure 14-16 shows the direction relative to a fixed axis of the maximum experienced acceleration at the CG of the target boat.

The pitch angle of the target boat was bow up at only five degrees at the time of maximum acceleration. The target boat never exceeded 12 degrees of bow up attitude during the collision. These values are significantly lower than the pitch up angles experienced during earlier experimental collisions. Pitch up angles as high as 38 degrees have been recorded.

Figure 14-17 shows what the direction of acceleration would be for the values given in the computer model with an increased pitch angle for the bullet boat. In this example, the occupant will feel as though he is being thrust to the floor of the boat. The force is nearly vertical to the trim angle of the boat in this example.

Obviously, if the boat is experiencing a rapid pitch acceleration, the occupants in the bow of the boat will be experiencing accelerations different from and probably more severe than those at the CG.

Only testing can confirm if the acceleration values depicted by the simulation are realistic. The simulation does suggest that the accelerations experienced by occupants of the bullet boat may be less than for a broad-side collision in an automobile.

Accelerations of the Target Boat

The peak accelerations of the target boat from the tabulated data were found to be as follows:

z axis : -95.8 ft/sec^2 or -63.6 ft/sec^2 when gravity is taken into account (-1.98 g's)

x axis : -120.9 ft/sec^2 or (3.75 g's)

Thus the total acceleration experienced by the target boat was 4.78 g's with gravity components taken into account. Note that these values are only slightly less than that experienced for the bullet boat. Remember that these values reflect peaks, and the time durations are small.

More meaningful data on accelerations could be obtained if the averages of acceleration curves for varying time periods during the collision were determined and compared for each boat.

Refer to Volume 2 for additional data on the simulation.

14.12 Potential Usefulness of Computers in the Future

14.12.1 Advantages and Future Applications

What did we actually learn by conducting the simulation? For one, we learned that it is both possible and feasible to conduct a computer simulation of a boating collision. The simulation was important not so much for the information gained from this particular simulation but for the opportunities and potential future applications.

Early in the project, experimentation was done with various values for hull stiffness and related parameters for the target boat. The initial attempts to model the hull structure of the target boat produced a boat that was too stiff to represent a fiberglass hull. The simulation runs did closely resemble an earlier experimental impact where a 19 foot open fishing boat struck an aluminum jonboat. This miscalculation demonstrated the potential usefulness of computer simulations for evaluating different collision scenarios, boat structures, and other variables.

Computer simulation has many potential applications in the future in the area of small boat collisions. Some of these potential applications would be to:

1. Increase understanding of boat and occupant dynamics during a collision;

2. Evaluate how different boat structures and designs perform during a collision;

3. Study how collisions affect the occupants in a boat and internal structures in a boat;

4. Reconstruct accidents.

When conducting a computer simulation of a collision using the techniques and tools used in this project, many advantages are available that support the above applications that may not be obvious. When using a computer, it is a simple matter to perform a variety of tasks in the computer model that in a real test are difficult or impossible to accomplish.

For example, if an engineer wanted to set up a real collision experiment, complete with instrumentation and all necessary equipment, the cost could be astronomical. It can also be difficult to set up instrumentation to accurately obtain instantaneous boat speeds, structural deflections, and pitch and roll rates. The computer however, once the model is set up, can provide virtually any data desired. Accurate values for speed, displacement, velocity, acceleration, energy, forces, deflections, and so forth can be obtained for any part of the model at any time. For

purposes of viewing and interpreting the results, the graphics available through SDI Animator provide an excellent presentation of the results. The numerical data is always available for a detailed analysis when desired, but for many situations the graphics may be all that is required.

It should be noted that the view of any collision from anywhere in the global reference frame is available. If it was desired to see what a collision may have looked like from an operator's perspective, it can be easily accomplished. Some graphics programs are available that even allow the programmer to experiment with simulation of various light sources and how the view of the surroundings is affected. This could someday be useful in evaluating night collisions or those which occur when the sun or glare is a factor.

Finally, one not so obvious advantage of conducting tests using a computer is that all of the inputs and variables can be precisely controlled. If it is desired to set the bullet boat's speed at 32.226 mph, it can be done. Try that with a real collision!

14.12.2 The Disadvantages

It is important to realize that a computer simulation is exactly that, a simulation. The output and the results are only as accurate and trustworthy as the accuracy of the model. Computers do not work magic, they simply execute instructions. They have no inherent knowledge of boats or dynamics, or anything else. When the video of the simulation conducted under this project is viewed, it does not look exactly like a real accident. Compared to what could be accomplished with additional research, time, and, of course, money, the model we produced is overly simplistic and really only useful as a starting point for future, more accurate, simulations.

The model and the collision we constructed involved the most simple scenarios imaginable, yet the equations and dynamics involved were fairly complex. More complex, realistic models are achievable, but would require significant additional research.

14.12.3 Feasibility of Application Of Computers to Boat Collisions

In the near term, the modeling of complex boat collisions as a general accident reconstruction tool is not really feasible. Additional research will need to be conducted before accurate collision models can be developed. In the meantime, computers may be helpful by serving purposes other than simulation of an accident.

Current software programs allow for computers to provide many support capabilities that can assist in the study and reconstruction of a collision. A summary of the potential applications is listed below:

1. Math programs are available that can assist in the solving and development of mathematical equations for boat accidents. For example, the equations and velocity ratio charts presented in Chapters 12 and 13 were performed using Mathcad 2.5, by Mathsoft, Inc.

2. A host of software is available to assist in performance prediction of planing hulls. This data can be used to predict trim angles, maximum speeds, stability characteristics and related parameters for a certain type or class of boats.

3. Animation software can be used to help illustrate a series of events as depicted by a witness. This type of software can produce output that is literally whatever the programmer wants it to be. It can be used as an effective tool for illustrating a sequence of events. This type of software is widely used in automobile accident reconstruction to help illustrate a complex sequence of events.

In summary, computers are not likely to serve as effective modeling tools for boat collisions in the near future; however, even today, computers and software may provide data that can be used to assist in the reconstruction of an accident.

14.12.4 Areas for Improvement of the Simulation Model

Many assumptions and simplifications were made for the purposes of this simulation. It was after all, a feasibility study. It is worthwhile to note some of the features of the model that were lacking and should be improved in future efforts. Suggested improvements are discussed below:

1. Both boats should be modeled using six degrees of freedom (DOF). In our simulation, the bullet boat was limited to three DOF.

2. The impact point should not necessarily be limited to the center of rotation (CR). Choosing the impact point co-incident with the CR prevented the target boat from yawing at impact. Modeling such rotation at impact would require further hydrodynamic data for the target boat.

3. The effects of the outdrive and lower unit should be modeled. The simulation presented only a graphic view of an outboard motor. It was not assigned any physical properties, and thus did not play any role in determining the impact response of either boat. Future simulations should include the effect of the outdrive on both boats. It will effect the CR of the target boat and the impact response of both boats. The outdrive could be modeled as a rigid body, but the characteristics which cause the outdrive to pivot upward when striking an object would need to be included in the model. It is not known if outdrive manufacturers have sufficient data which would allow an accurate model to be developed.

4. The friction model should be improved. The friction model should be made as accurate as possible. Admittedly, this would require data not currently available to obtain the actual friction coefficients experienced during an impact.

5. The hydrodynamic model for lateral movement of the target boat through the water should be improved.

6. The model of the structure of the target boat should be improved. Laboratory testing of hull side panels and even whole boat hulls could be used to provide data for a force vs. deflection curve prior to impact and also for the energy required for penetration.

7. Occupants should be placed in the interior of both boats. The software and technology is currently available that will allow the reaction of an occupant to be modeled during the collision. In the early stages, this may provide only gross approximations. Sufficient data could probably be generated to determine if the occupants would be thrown out of the boat.

14.12.5 Benefits in Human Factors and Occupant Protection

ADAMS has a module available called ADAMS/Android. According to literature from Mechanical Dynamics, Inc., the ADAMS/Android model "makes it possible to construct and modify a human 'body' in less than ten minutes, based on factors such as gender, population percentile and activity." The potential applications of this software with regard to occupant protection and human factors are promising.

The automobile industry started crashing automobiles many years ago to obtain data on vehicle performance during a crash and to study the affects of the crash on the occupants. In the early days of this testing, there was simply no other method of obtaining the necessary data.

If for any reason, it becomes desirable or necessary in the future to evaluate the affects of a particular boat's design on its occupants during a certain type of collision, ADAMS/Android may provide the basis for doing so on a more cost effective and more controlled basis.

14.13 Conclusions and Recommendations

The computer is a powerful tool that holds great promise for the future of boat accident reconstruction. Full scale dynamic simulation of boat collisions will require some additional research and instrumented test crashes as a basis before a computer model can be used as a valid reconstruction or simulation tool. Based on the research conducted thus far, simulation of boat collisions appears quite feasible in the long run. The prospect of being able to model a collision with a reasonable degree of accuracy in the near future depends on the amount of effort put towards conducting research to fill in some of the missing pieces.

UL recommends that the USCG carefully examine the benefits offered by this technology, primarily for what it could offer the boating industry in the areas of modeling as it applies to occupant protection. The computer can serve as a great tool for simulating boat dynamics and predicting the resultant occupant responses. Once an accurate computer model is established, this method may prove much more cost effective than conducting real collisions to obtain such data.

Until such time as full scale simulations are possible, the methods and potential applications discussed in Chapters 11, 12 and 13 could be more fully developed as accident reconstruction tools.

References for Chapter 14

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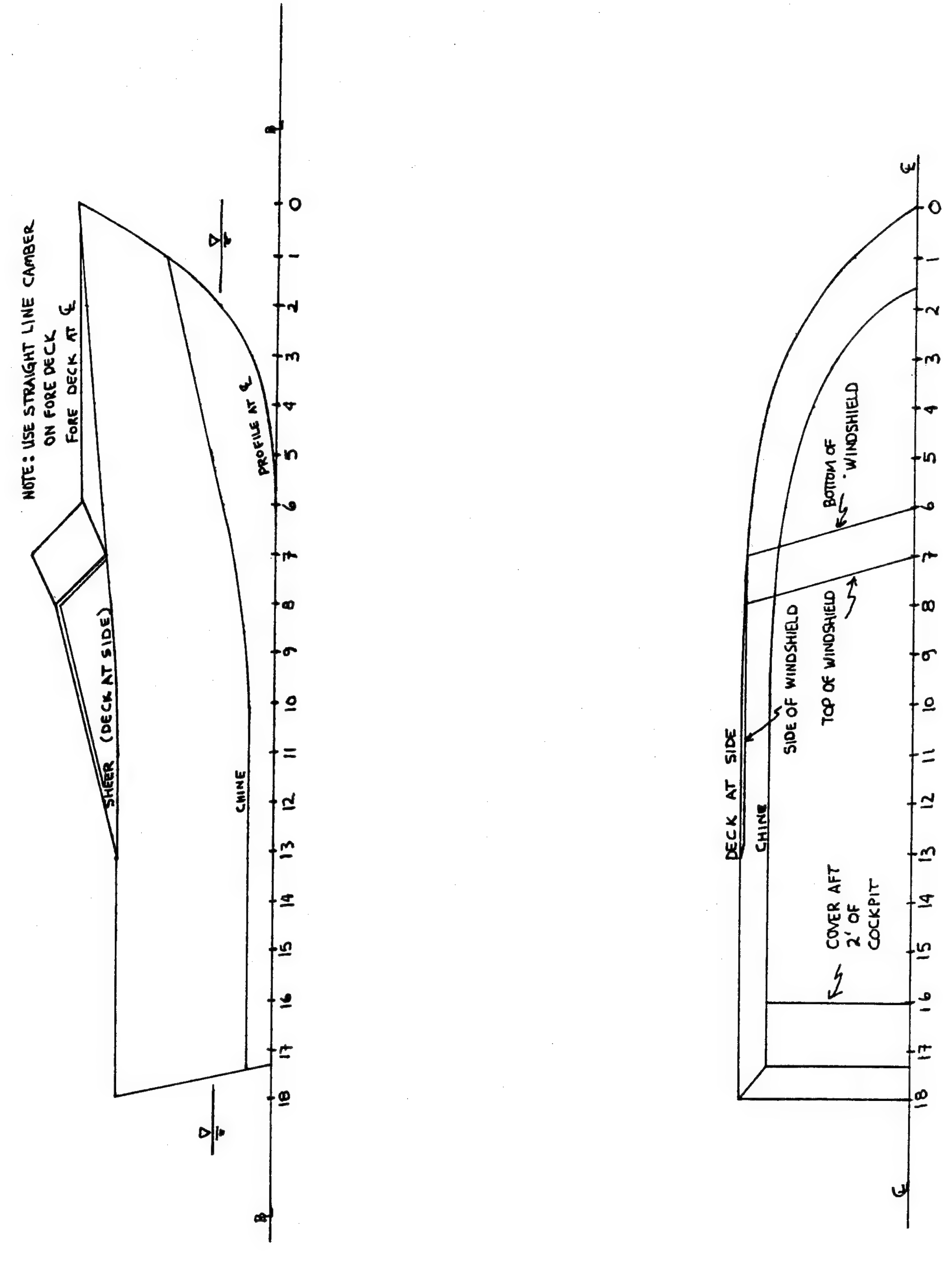
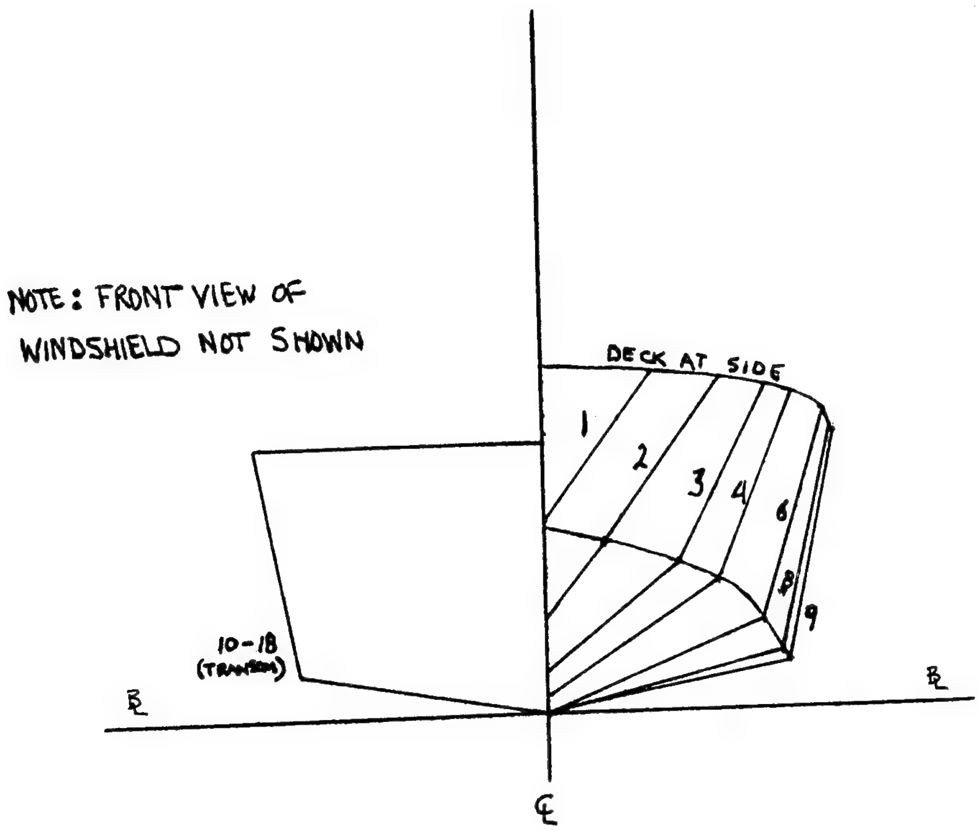


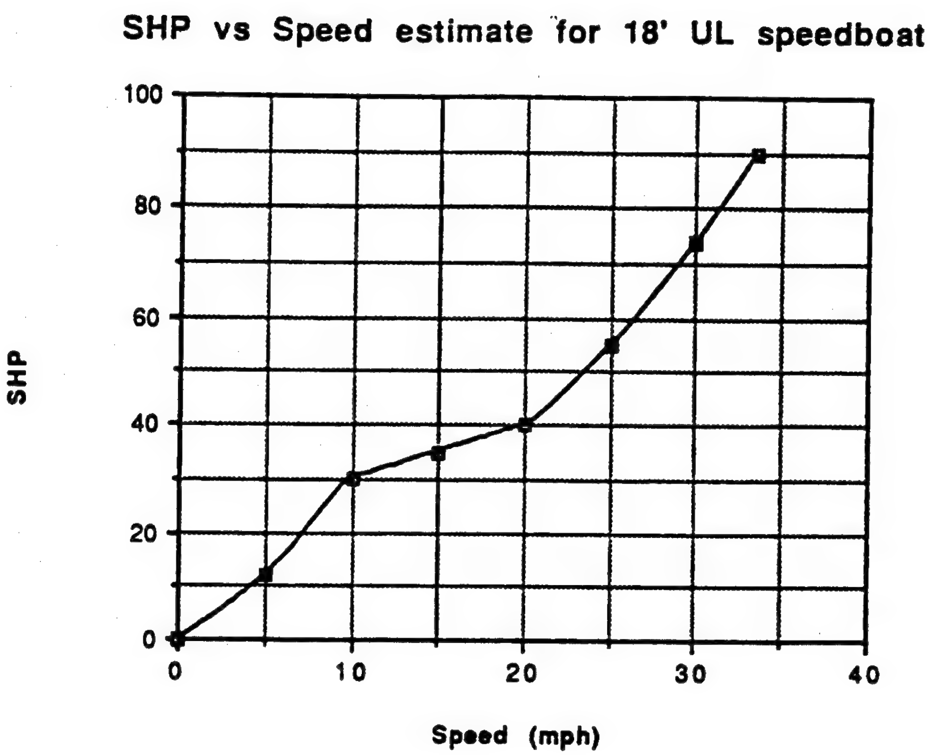
The Boat Used in the Computer Simulation.

Figure 14-1



The Boat Used in the Computer Simulation.

Figure 14-2


SHP vs Speed estimate for 18' UL speedboat
100
80
60
40
20
0
SHP
0
10
20
30
40
Speed (mph)

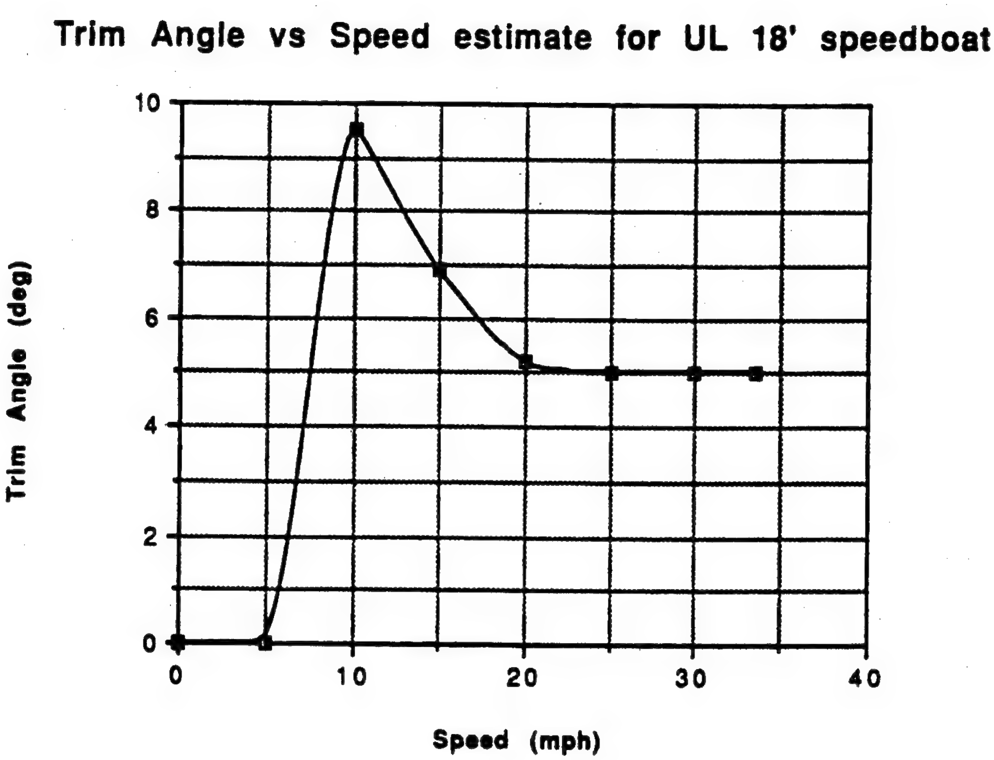
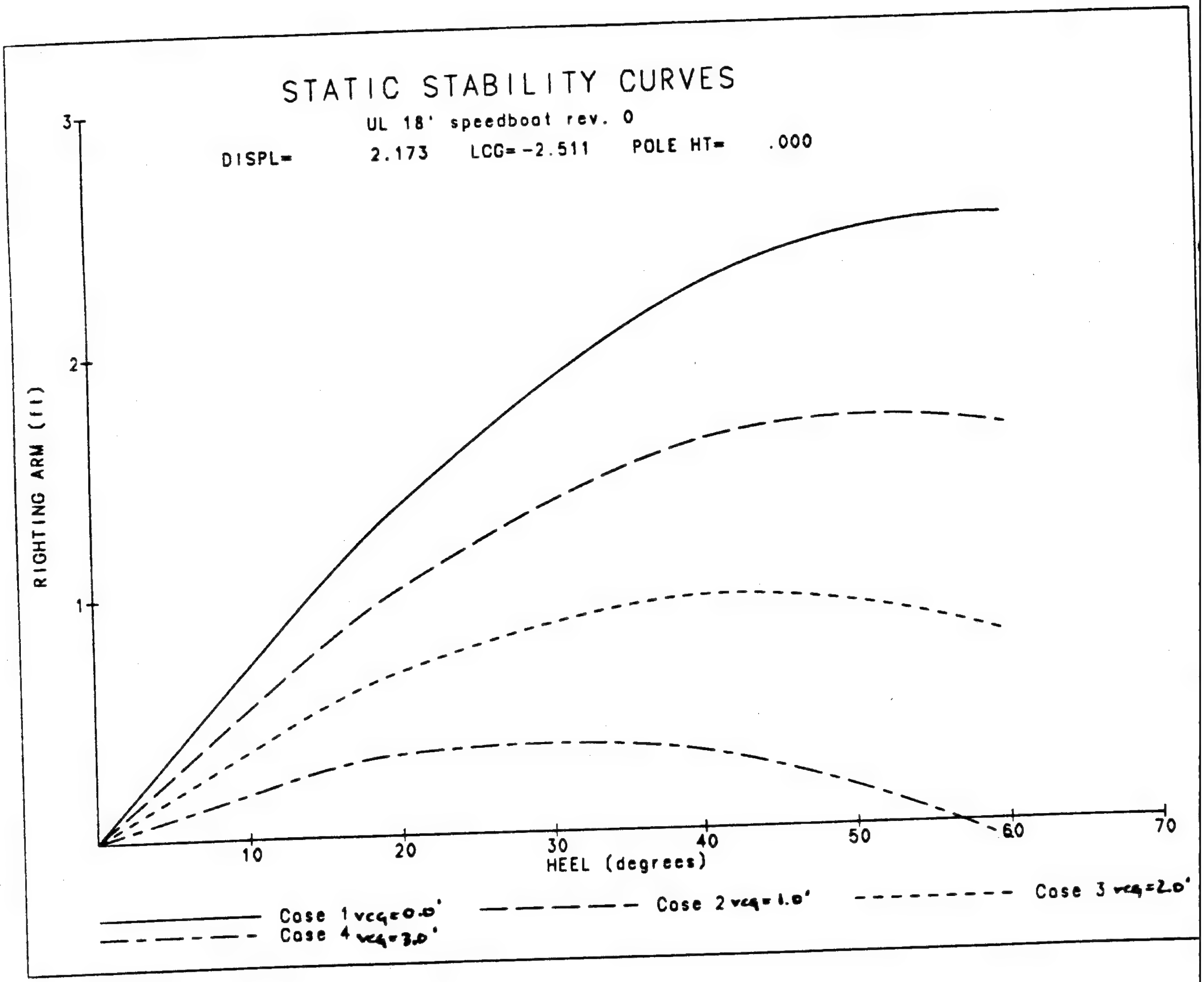
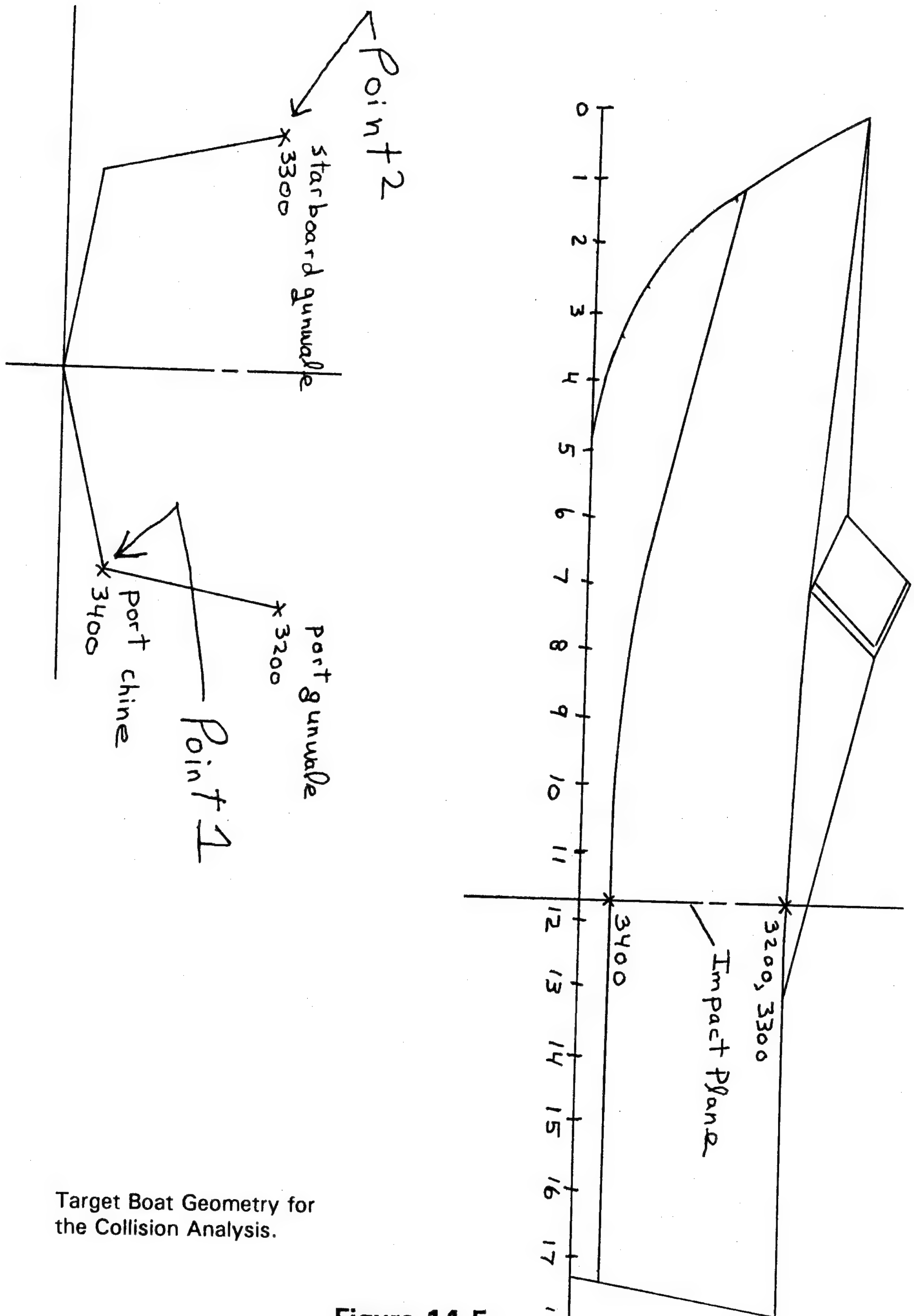

Trim Angle vs Speed estimate for UL 18' speedboat
10
8
6
4
2
0
Trim Angle (deg)
0
10
20
30
40
Speed (mph)

Figure 14-3



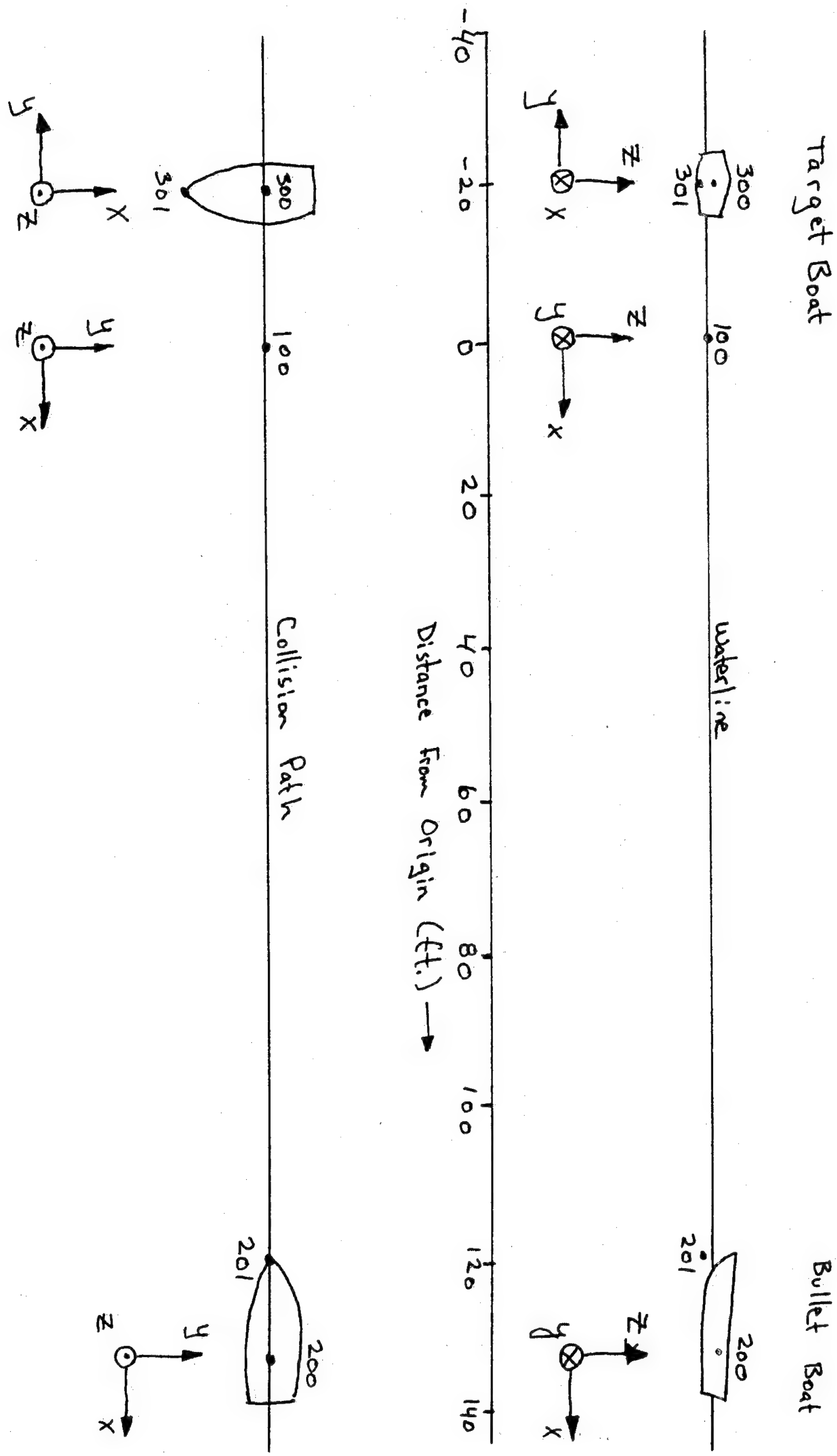
STATIC STABILITY CURVES
UL 18' speedboat rev. 0
DISPL= 2.173 LCG= -2.511 POLE HT= .000
RIGHTING ARM (ft)
3
2
1
10
20
30
40
50
60
70
HEEL (degrees)
Case 1 vcg=0.0'
Case 2 vcg=1.0'
Case 3 vcg=2.0'
Case 4 vcg=3.0'

Figure 14-4



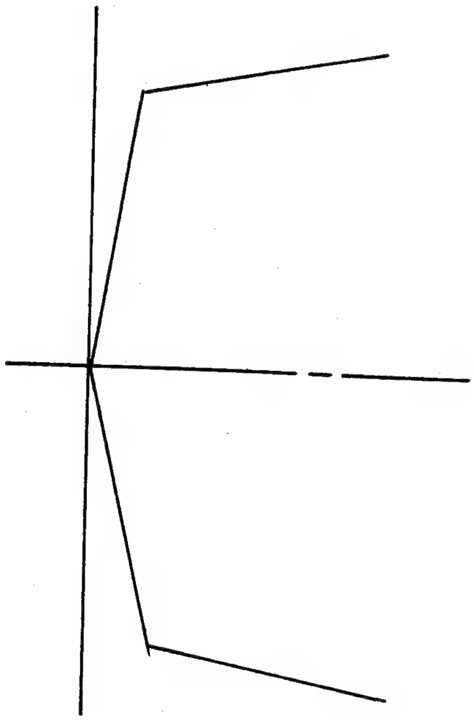
Target Boat Geometry for the Collision Analysis.

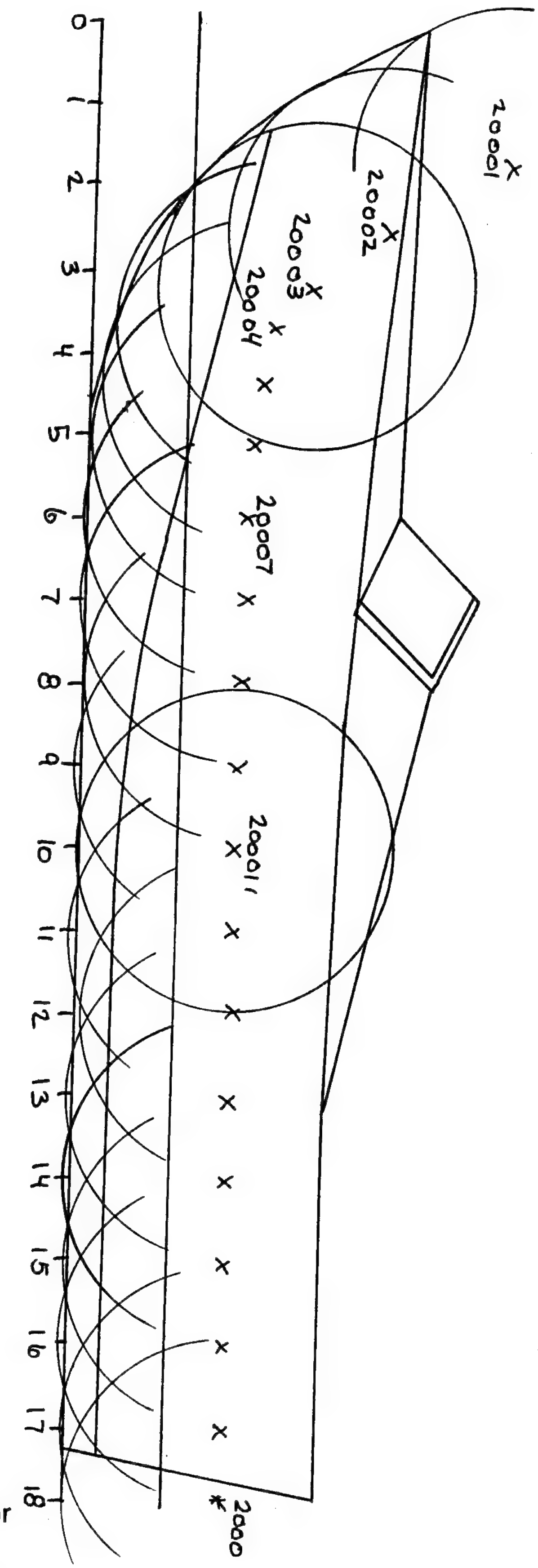
Figure 14-5



Basic Geometry of the 30 mph Collision.

Figure 14-6





Bullet Boat Geometry for the Collision Analysis.

Figure 14-7

LIST OF GRAPHS PROVIDED FOR THE 30 MPH COLLISION

ReqNo.	Col.	Axis	Parameter
2001	1	Y	BB Displacement
2002	1	Y	BB Velocity
2003	1	Y	BB Acceleration
2001	3	Z	BB Displacement
2002	3	Z	BB Velocity
2003	3	Z	BB Acceleration
2004	3	Z	BB Forces (Buoyant)
2001	5	Pitch	BB Displacement
2002	5	Pitch	BB Velocity
2003	5	Pitch	BB Acceleration
2001	1,3	X,Z	BB CG Disp (Z) vs BB CG Disp (X) (CG Trajectory)
3001	1	X	TB Displacement
3002	1	X	TB Velocity
3003	1	X	TB Acceleration
3001	3	Z	TB Displacement
3002	3	Z	TB Velocity
3003	3	Z	TB Acceleration
3004	3	Z	TB Forces (Buoyant Forces)
3001	5	Pitch	TB Displacement
3002	5	Pitch	TB Velocity
3003	5	Pitch	TB Acceleration

Force Diagrams

Port Gunwale Impact Forces
(First two of 19 impact fields)

Starboard Gunwale Impact Forces
(Five impact fields)

Port Chine Impact Forces
(Three impact fields)

Total Port Gunwale Impact Force
Total Starboard Gunwale Impact Force
Total Port Chine Impact Force
Total Impact Force

Key:

Col 1 = x axis
Col 2 = y axis
Col 3 = z axis

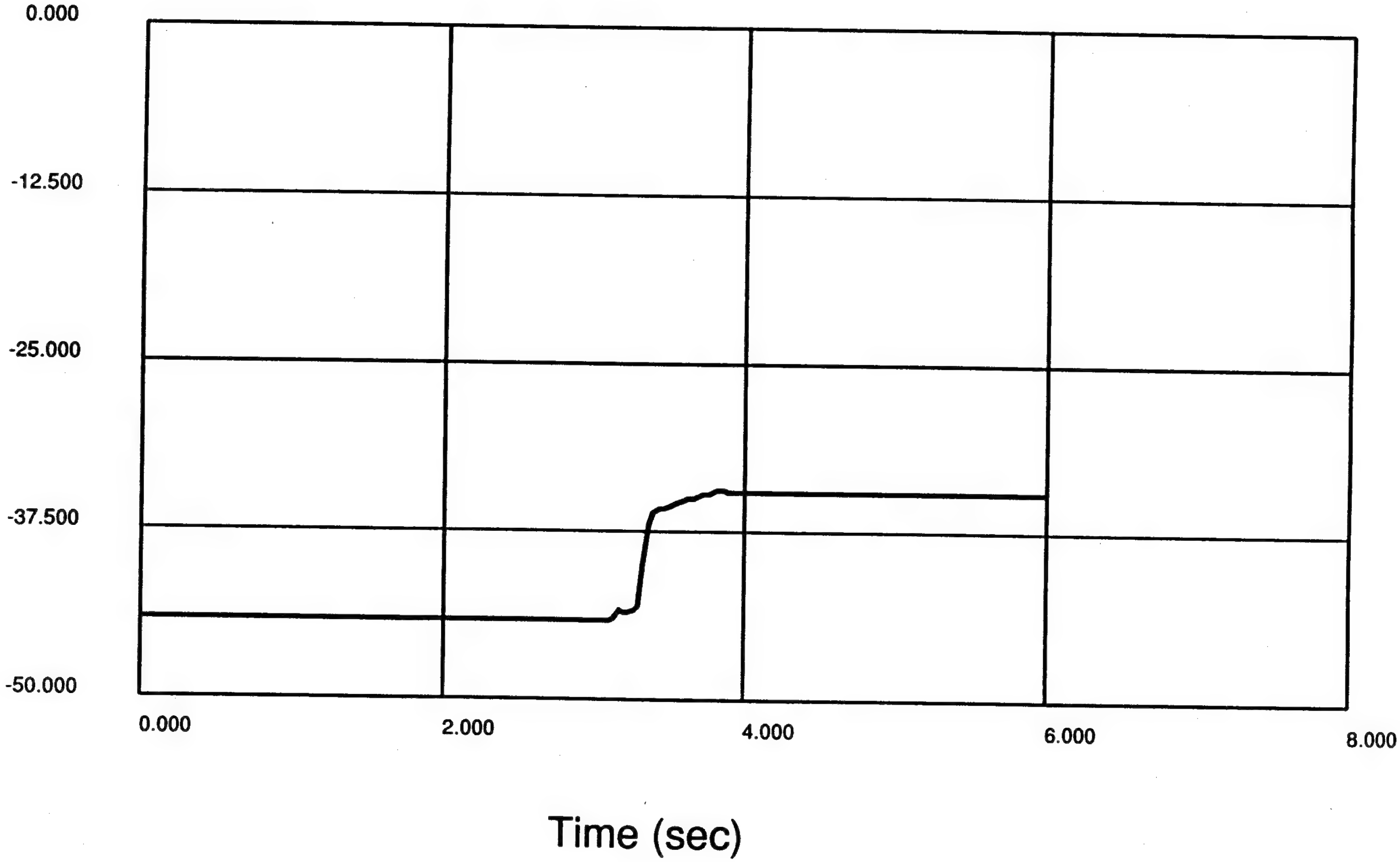
Col 4 = Yaw
Col 5 = Pitch
Col 6 = Roll

BB = Bullet Boat
TB = Target Boat

Figure 14-8

Req 2002, Col 1, Bullet Boat Velocity $\left(\frac{ft}{sec}\right)$

X- Axis



BAP 9111(

Figure 14-9

Req 2002, Col 3, Bullet Boat Velocity $\left(\frac{ft}{sec}\right)$

Z - Axis

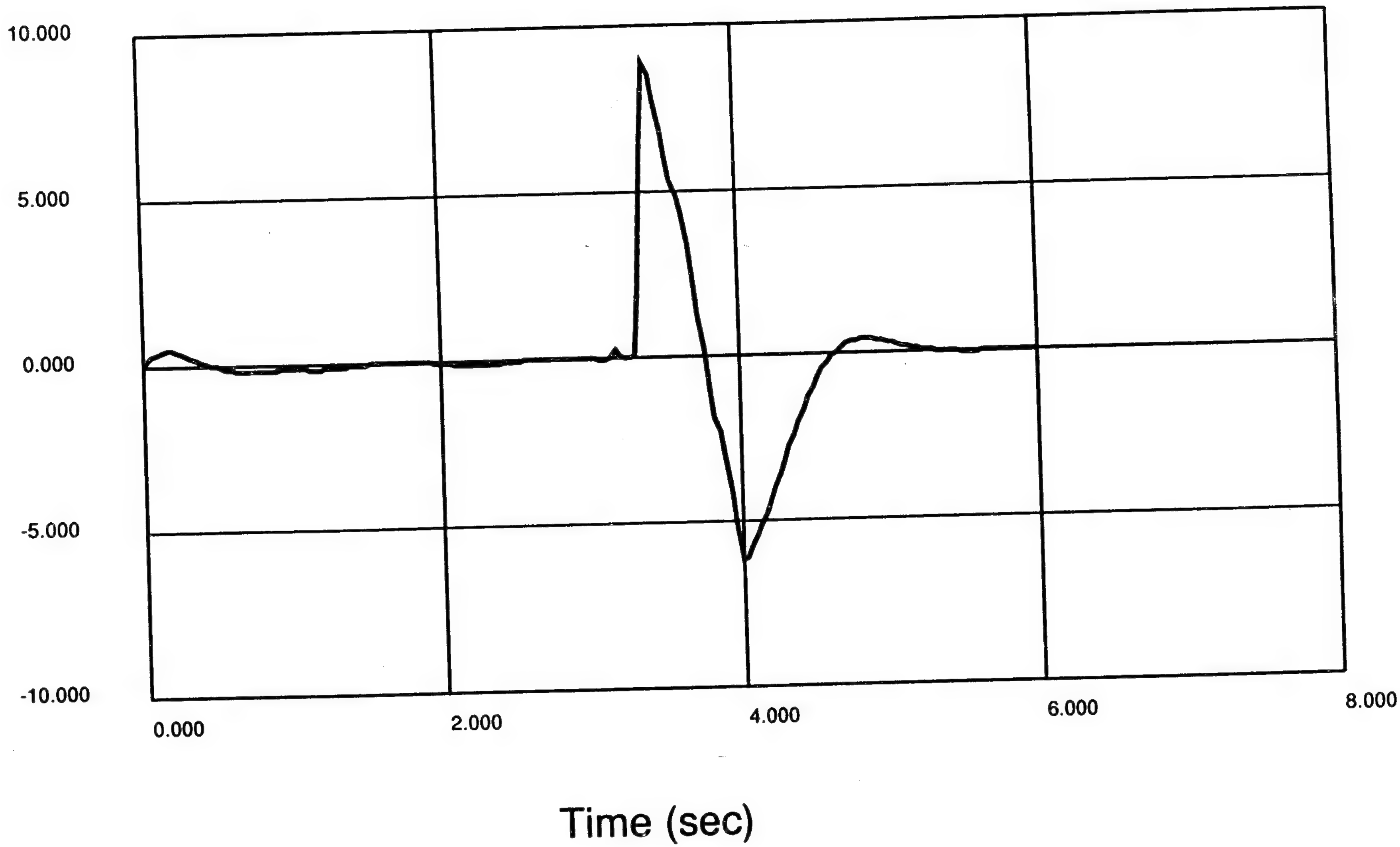
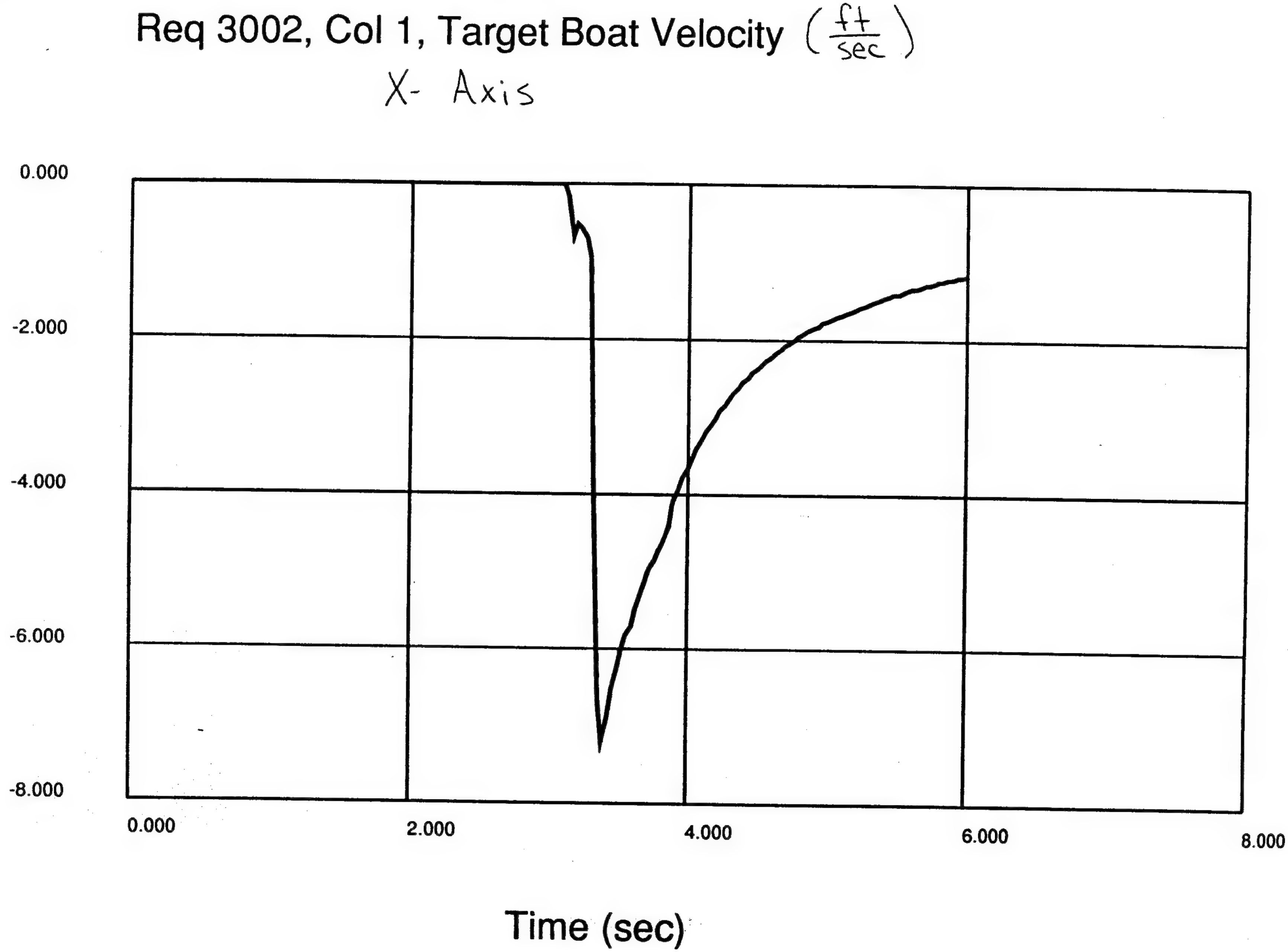


Figure 14-10

BAP 9111C



Req 3002, Col 1, Target Boat Velocity ($\frac{ft}{sec}$)
X- Axis
0.000
-2.000
-4.000
-6.000
-8.000
0.000
2.000
4.000
6.000
8.000
Time (sec)

Figure 14-11

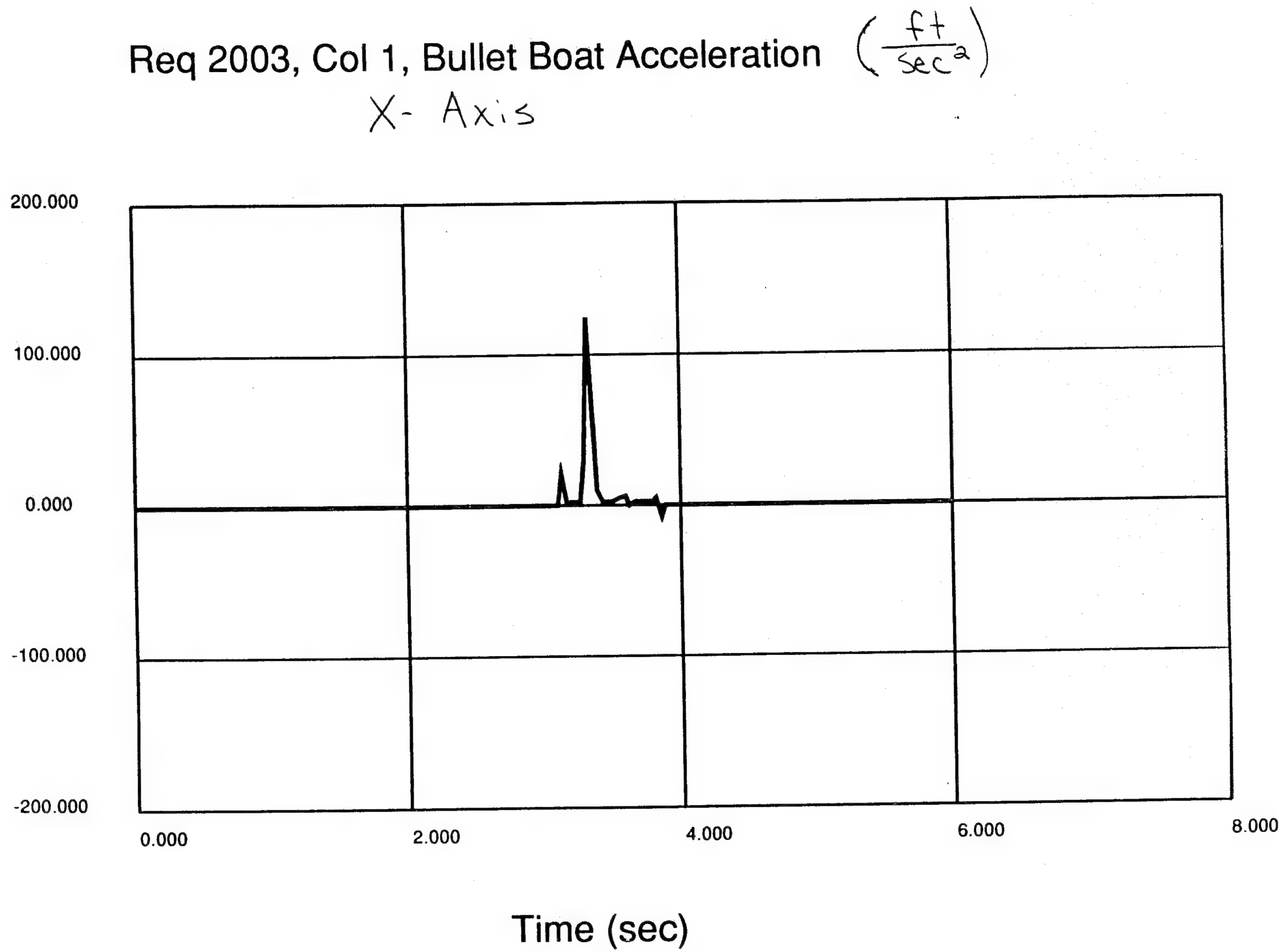

Req 2003, Col 1, Bullet Boat Acceleration $\left(\frac{ft}{sec^2}\right)$
X- Axis
200.000
100.000
0.000
-100.000
-200.000
0.000
2.000
4.000
6.000
8.000
Time (sec)

Figure 14-12

Req 2003, Col 3, Bullet Boat Acceleration $\left(\frac{ft}{sec^2}\right)$

Z - Axis

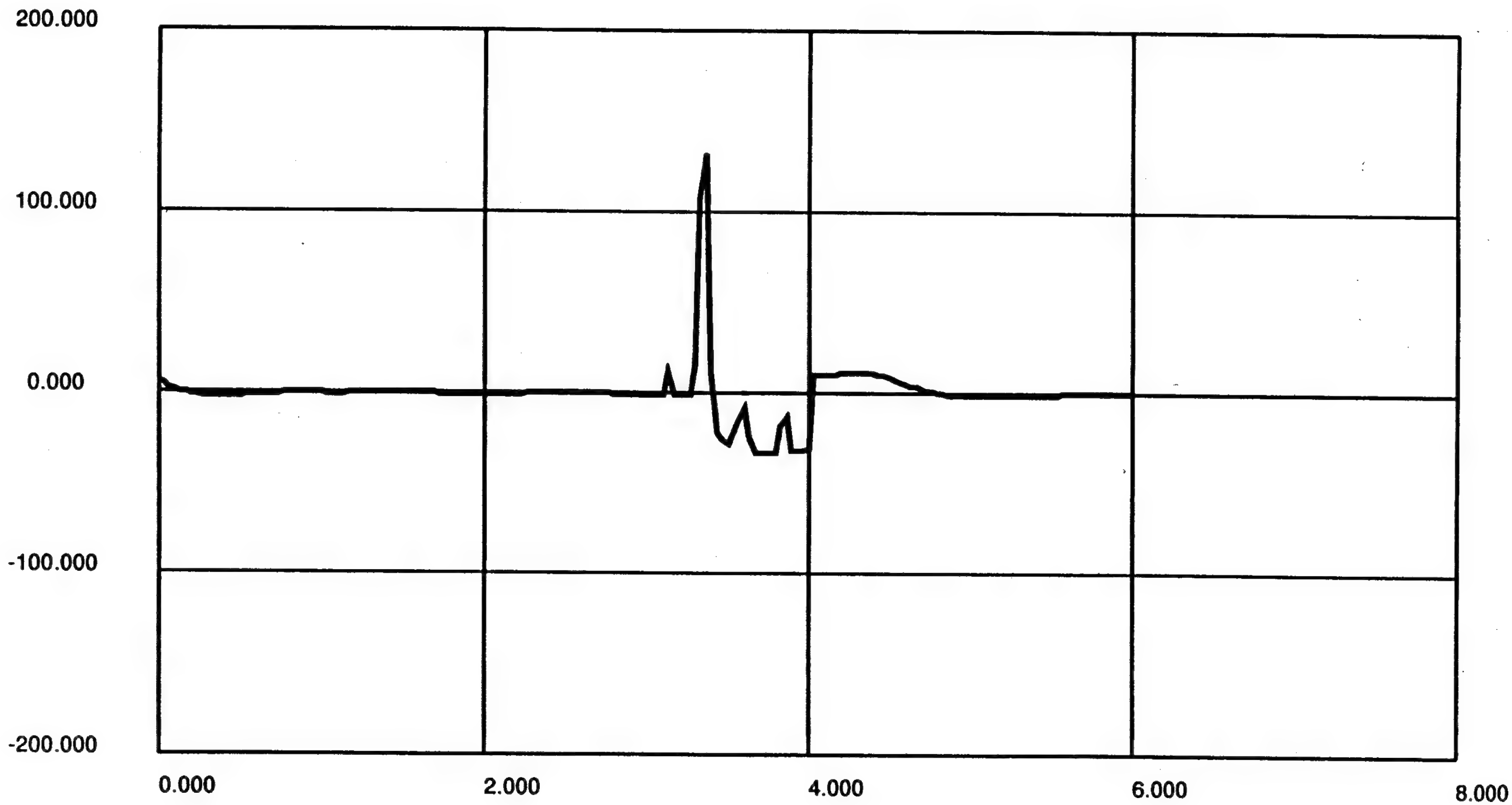


Figure 14-13

BAP 91110

Req 3003, Col 1, Target Boat Acceleration $\left(\frac{ft}{sec^2}\right)$

X- Axis

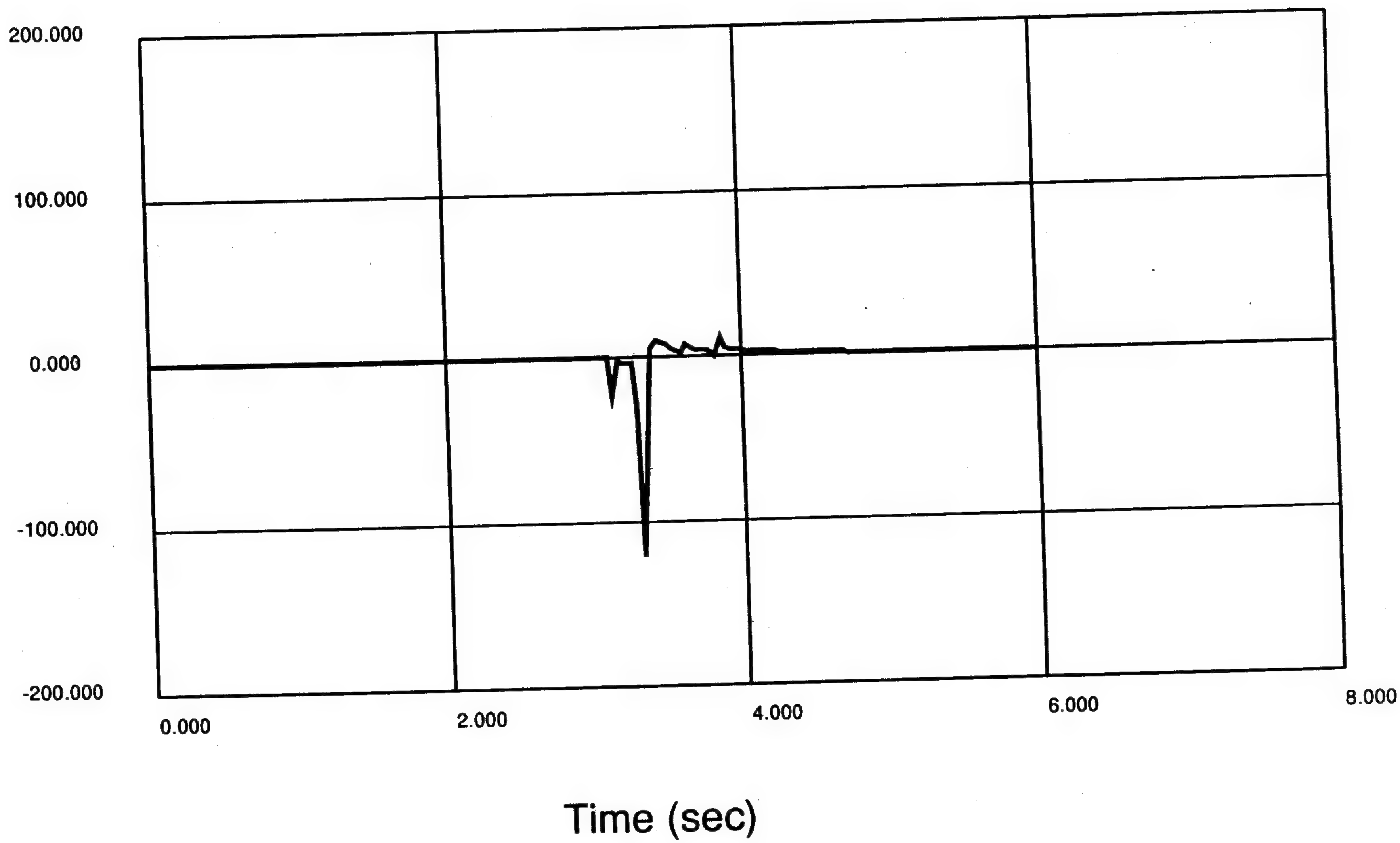


Figure 14-14

BAP 9111

Req 3003, Col 3, Target Boat Acceleration $\left(\frac{ft}{sec^2}\right)$

Z - Axis

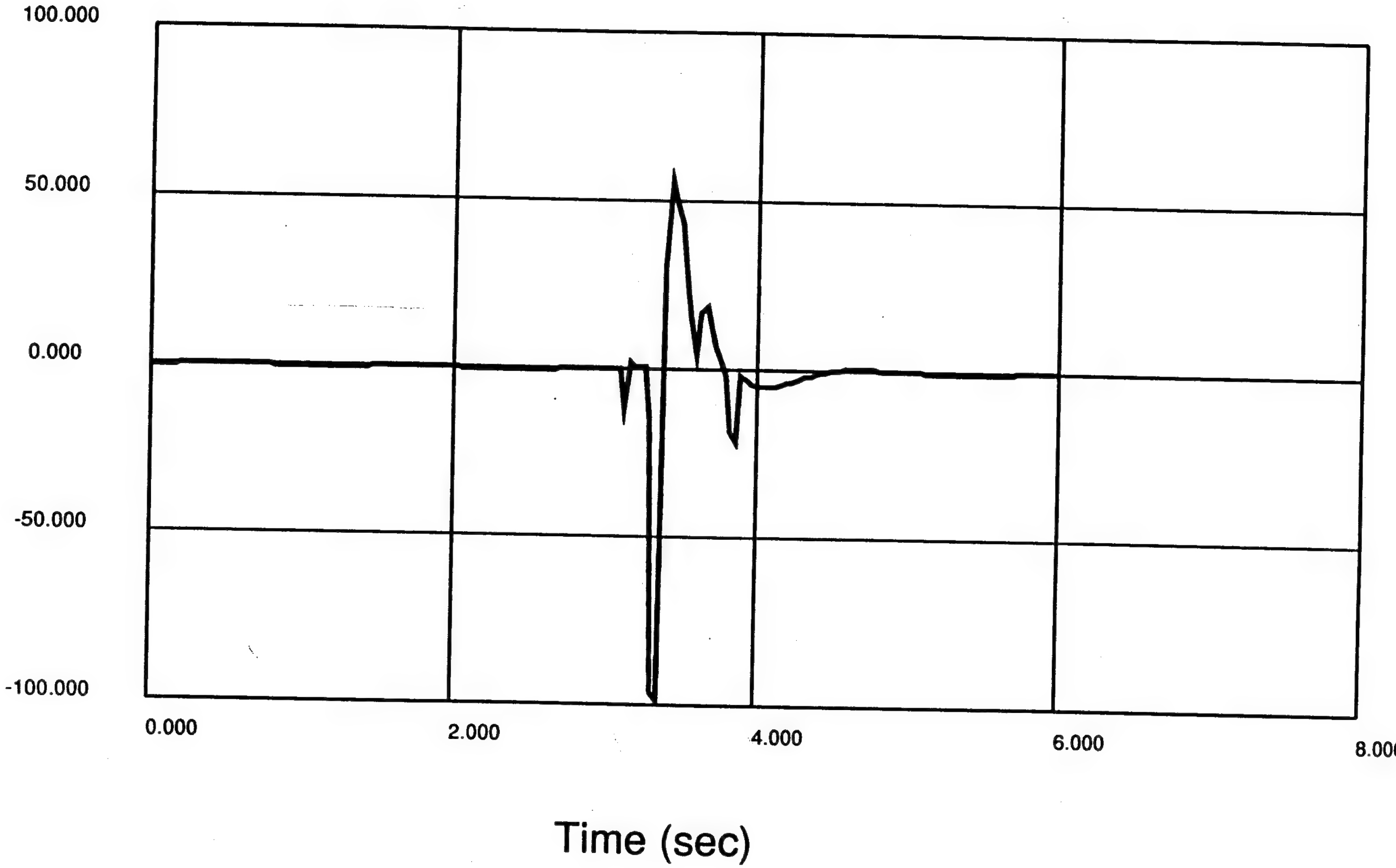
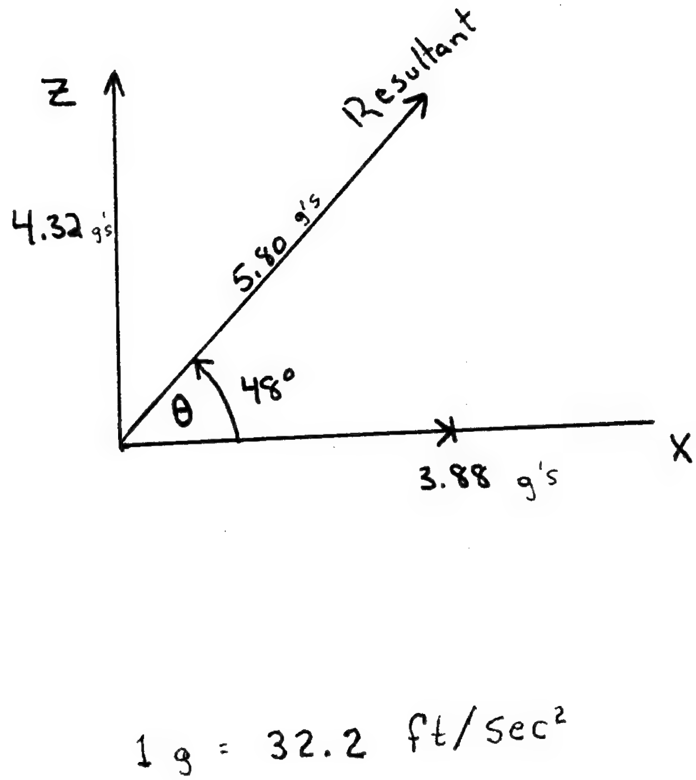


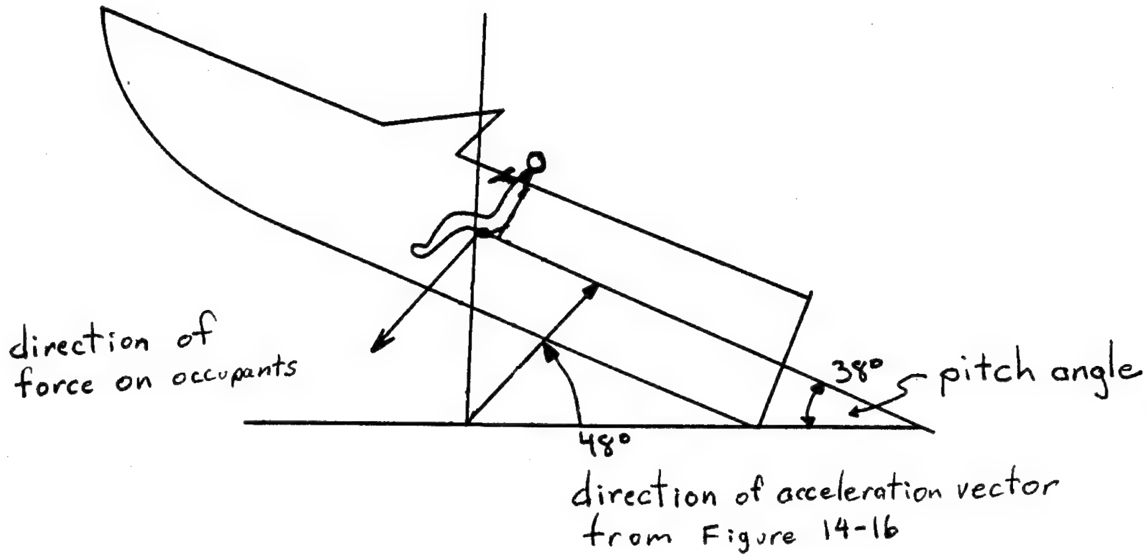
Figure 14-15

BAP 91110



Resultant Acceleration Vector of the
Bullet Boat CG During Impact.

Figure 14-16



Occupants of the Bullet Boat at the CG Experience a Force Opposite in Direction to the Total Acceleration Vector of the CG.

Figure 14-17

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